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(54) APPARATUS AND METHOD FOR LOCATING A MEDICAL TUBE IN THE BODY OF A PATIENT

VORRICHTUNG UND VERFAHREN ZUM LOKALISIEREN EINER MEDIZINALRÖHRE IM KÖRPER EINES PATIENTEN

APPAREIL ET PROCEDE DE LOCALISATION D'UN TUBE MEDICAL DANS LE CORPS D'UN PATIENT

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- **PATENT ABSTRACTS OF JAPAN vol. 14, no. 165 (P-1030) 30 March 1990 & JP,A,02 021 290 (SHIMIZU SHOHACHI)**

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Description

Technical Field

[0001] This invention is generally directed to an apparatus and method for detecting the location of a medical tube within the body of a patient and, more specifically, to detecting the location of a medical tube using a detection apparatus which senses a static magnetic field strength gradient generated by a magnet associated with the medical tube.

Background of the Invention

[0002] There are many instances in clinical medicine where detecting the location of a medical tube within a patient is important. For example, when positioning feeding tubes through the mouth or nose of a patient, it is essential that the end of the feeding tube pass into the patient's stomach, and that it does not "curl up" and remain in the esophagus. If the end of the feeding tube is not properly positioned within the stomach, aspiration of the feeding solution into the patient's lungs may occur. In addition to feeding tubes, a variety of other medical tubes require accurate positioning within a patient's body, including dilating tubes to widen an esophageal stricture, tubes for measuring pressure waves in the stomach and esophagus of a patient who is suspected of having esophageal motor disorders, Sengstaken-Blakemore tubes in the stomach and esophagus of a patient to control bleeding from varicose veins in the esophagus, colonic decompression tubes in the colon of a patient to assist in relieving distention of the colon by gas, urologic tubes in the bladder, ureter or kidney of a patient, and vascular tubes in the heart or pulmonary arteries of a patient.

[0003] Currently, the location of a medical tube within the body of a patient is routinely detected by the use of imaging equipment, such as a chest or abdominal X-ray. However, such a procedure requires transportation of the patient to an X-ray facility or, conversely, transportation of the X-ray equipment to the patient. This is both inconvenient and costly to the patient, and is particularly stressful in those instances where the patient repeatedly and inadvertently removes a medical tube, such as a feeding tube, thus requiring repeated reinsertion and X-rays.

[0004] Prior attempts at detecting the location of medical tubes within a patient have met with only limited success. For example, in U.S. Patent No. 5,099,845 to Besz et al., a transmitter is located within a catheter, and an external receiver, tuned to the frequency of the transmitter, is used to detect the location of the catheter within the patient. This approach, however, requires either an external or internal power source to drive the transmitter. An external power source adds significant risk associated with shock or electrocution, and requires that electrical connections be made prior to positioning of the catheter within the patient. An internal power source, such as a battery, must be relatively small and can only provide power to the transmitter for a limited time. This precludes long-term detection of the catheter's location, and poses additional risks associated with placing a battery internally in a patient, such as the risk of battery leakage or rupture. In addition, the transmitter is relatively complex, and requires an active electronic circuit (either internal or external to the catheter), as well as the various wires and connections necessary for its proper function. Lastly, the signal produced by the transmitter is attenuated differently by different body tissues and bone. This attenuation requires adjustments in the transmitter's signal strength and frequency depending on the location of the catheter within the patient's body.

[0005] A further attempt at detecting the location of medical tubes within a patient is disclosed in U.S. Patent No. 4,809,713 to Grayzel. There, an electrical cardiacpacing catheter is held in place against the inner heart wall of a patient by the attraction between a small magnet located in the tip of the pacing catheter and a large magnet located on (e.g., sewn into) the patient's chest wall. An indexed, gimbaled, three-dimensional compass is used to determine the best location for the large magnet. The compass' operation relies upon the torque generated by the magnetic forces between the small magnet and the magnetized compass pointer in order to point the compass towards the small magnet. However, this compass will simultaneously try to orient itself to the earth's ambient magnetic field. Because of this, the forces between the small magnet and the magnetized compass pointer at distances greater than several centimeters are not strong enough to accurately orient the compass towards the small magnet. Furthermore, although the compass aids positioning of the large magnet, positioning of the small magnet, and hence the pacing catheter, still requires the use of imaging equipment, such as X-ray or ultrasound.

[0006] For the foregoing reasons, there is a need in the art for an apparatus and method for detecting the location of a medical tube within the body of a patient which avoids the problems inherent in existing techniques. The apparatus and method should provide for the detection of the medical tube at distances ranging from several centimeters to several decimeters, should not require the medical tube to have an internal or external power source, and should obviate the need to independently verify positioning of the medical tube with imaging equipment.

[0007] GB-A-2 102 127 discloses an apparatus for determining the position of a device which generates a small magnetic field within a patient's body. An electromagnetic probe is located near the magnetic device, the magnetic field of the device disturbing the magnetic field of the probe sensors resulting in unequal currents in the respective probe coils. The unequal currents are used to drive a speaker to provide an audible signal and a number of LEDs to provide a visual signal.

[0008] US-A-3 649 908 discloses a magnetic field gradiometer which provides a signal indicative of the gradient in a DC magnetic field.

Summary of the Invention

[0009] Accordingly, it is an object of the present invention to provide an apparatus and method for detecting the location of a medical tube within the body of an animal patient (including humans) without the aid of imaging equipment, particularly X-ray. It is a further object to detect the location of the medical tube without relying upon torque generated by the magnetic forces between the medical tube and the detection apparatus. Yet, a further object is to detect the location of the medical tube while dynamically nulling sensing of the earth's ambient magnetic field, and to thereby allow detection distances suitable for locating a wide variety of medical tubes at any location within the body of the patient.

[0010] The present invention satisfies these objectives by providing an apparatus and method for detecting the location of a magnet associated with a medical tube within the body of a patient. In one aspect of this invention, the apparatus of this invention comprises a system for detecting the location of a magnet associated with a medical tube within the body of a patient in the presence of the Earth's magnetic field, the system comprising a magnet (91) associated with a medical tube (90) to be, in operation, inserted into the body of a patient and a detector, the detector (80) comprising: means for sensing a first static magnetic field strength and providing a first sensor signal which is a function of the first static magnetic field strength; means for sensing a second static magnetic field strength and providing a second sensor signal which is a function of the second static magnetic field strength, wherein the means for sensing the first static magnetic field strength (10) and the means for serving the second static magnetic field strength (20) are separated by a predeterminate distance; means for receiving the first sensor signal and providing a first detection signal which is a function of the first sensor signal; means for receiving the second sensor signal and providing a second detection signal which is a function of the second sensor signal; means for receiving the first and second detection signals and providing a differential signal which is a function of the difference between the first detection signal and the second detection signal; and means for receiving and indicating a value for the differential signal. The first and second detection signals and the differential signal can be scalars or vectors.

[0011] The first and second sensing means also provide, respectively, a first sensor signal, which is a function of the first static magnetic field strength, and a second sensor signal, which is a function of the second static magnetic field strength. The means for providing the first detection signal receives the first sensor signal, and the means for providing the second detection signal receives the second sensor signal. Finally, the means for providing the differential signal receives the first and second detection signals, and the means for indicating the differential signal's value receives the differential signal. The first and second sensor signals can be scalars or vectors.

[0012] By sensing the static magnetic field strength of the magnet associated with the medical tube, the present invention obviates the need for imaging equipment, such as X-ray, to verify positioning of the medical tube. Also, by sensing the magnet's field strength at two different distances (i.e., the first and second distances) from the magnet between which the magnet's field strength will have a gradient and the earth's field strength will not, and by indicating the gradient to the user, the present invention dynamically nulls sensing of the earth's ambient magnetic field. This nulling allows the magnet to be sensed at distances ranging from several centimeters to several decimeters, which makes the detection apparatus suitable for locating the medical tube at any location within the patient's body.

[0013] In one embodiment of this invention, the first and second sensing means comprise a static magnetic field strength sensor driver, and first and second static magnetic field strength sensors. The driver provides a driver signal which causes the sensors to provide the first and second sensor signals. In a preferred embodiment, the driver comprises an oscillator and output transistors, wherein the output transistors are alternately switched by the oscillator and are thereby caused to provide the driver signal. The sensors each comprise a fluxgate toroidal sensor, which includes an excitation winding which receives a driver signal, and a detection winding which provides the respective sensor signal. By providing a driver signal which causes the sensors to provide the first and second sensor signals, the present invention does not need to rely upon magnetic forces between the magnet and the apparatus for detecting the location of the medical tube.

[0014] In another embodiment, the detection apparatus further comprises a means for automatically controlling, monitoring, and calibrating (a) the first and second means for sensing the first and second static magnetic field strengths; (b) the means for providing the first detection signal; (c) the means for providing the second detection signal; (d) the means for providing the differential signal; and (e) the means for indicating the differential signal's value. In a preferred embodiment, the automatic controlling, monitoring, and calibrating means is a microprocessor.

[0015] In an embodiment of this invention, the apparatus of this invention comprises the static magnetic field strength sensor driver, the first and second static magnetic field strength sensors, first and second amplifiers, first and second integrators, a differential amplifier, a magnitude circuit, a visual display driver, and a visual display.

[0016] The first amplifier receives the first sensor sig-

nal and provides a first amplified signal which is proportional to the first sensor signal. Similarly, the second amplifier receives the second sensor signal and provides a second amplified signal which is proportional to the first sensor signal. The first and second amplified signals can be scalars or vectors.

[0017] The first and second integrators receive the first and second amplified signals, respectively, and provide the first and second detection signals, respectively. The differential amplifier receives the first and second detection signals and provides the differential signal.

[0018] Further, the magnitude circuit receives the differential signal and provides a magnitude signal which is proportional to the magnitude of the differential signal. The visual display driver receives the magnitude signal and provides a visual display signal. The visual display receives and visually indicates the visual display signal.

[0019] In a preferred embodiment, the visual display driver comprises a light emitting diode bar array driver, and the visual display comprises a light emitting diode bar array.

[0020] In another preferred embodiment, the apparatus further comprises a tone generator for receiving the magnitude signal and providing a tone signal which is a function of the magnitude signal, and a speaker for receiving and audibly indicating the tone signal.

[0021] In still another preferred embodiment, the apparatus further comprises a polarity circuit for receiving the differential signal and providing a polarity signal which is a function of the polarity of the differential signal, a polarity display driver for receiving the polarity signal and providing a polarity display signal, and a polarity display for receiving and visually indicating the polarity display signal.

[0022] In still another preferred embodiment, the apparatus further comprises the microprocessor for automatically controlling, monitoring and calibrating the static magnetic field strength sensor driver, the first amplifier, the second amplifier, the differential amplifier and the visual display driver.

[0023] In a further embodiment of this invention, the detection apparatus comprises first and second static magnetic field strength sensors, first and second detectors, a microprocessor, a magnitude circuit, and an indicator. In this embodiment, the first and second sensor signals, the first and second detection signals, and the differential signal are vectors.

[0024] The first detector receives the first sensor signal and provides the first detection signal which is a function of the first sensor signal. Similarly, the second detector receives the second sensor signal and provides the second detection signal which is a function of the second sensor signal. The microprocessor receives the first and second detection signals and provides the differential signal which is a function of the difference between the first and second detection signals.

[0025] In a preferred embodiment, the first sensor includes x, y, and z-axis oscillators which provide x, y, and z components, respectively, of the first sensor signal. Each oscillator of the first sensor has an associated wound-core inductive sensor. The x, y, and z components are functions of the inductance of the inductive sensor of the components' respective oscillators, and the inductance is a function of the first static magnetic field strength. Likewise, the second sensor includes x, y, and z-axis oscillators which provide x, y, and z components, respectively, of the second sensor signal, and each oscillator of the second sensor has an associated wound-core inductive sensor. The x, y, and z components are functions of the inductance of the inductive sensor of the components' respective oscillators, and the inductance is a function of the second static magnetic field strength.

[0026] In a further preferred embodiment, the first detector includes x, y, and z-axis frequency counters which receive the x, y, and z components, respectively, of the first sensor signal, and provide x, y, and z components of the first detection signal. Similarly, the second detector includes x, y, and z-axis frequency counters which receive the x, y, and z components, respectively, of the second sensor signal, and provide x, y, and z components of the second detection signal.

[0027] In still another aspect of this invention, a method for detecting the location of a magnet associated with a medical tube within the body of a patient, comprising: sensing a first static magnetic field strength at a first distance from the magnet; sensing a second static magnetic field strength at a second distance from the magnet which is greater than the first distance; providing a first sensor signal which is a function of the first static magnetic field strength; providing a second sensor signal which is a function of the second static magnetic field strength; receiving the first and second sensor signals and providing a differential signal which is a function of the difference between the first static magnetic field strength and the second static magnetic field strength; receiving and indicating a value for the differential signal; and determining the location of the medical tube by varying the first and second distances until the greatest value for the differential signal is indicated.

[0028] In a preferred embodiment, providing the first sensor signal includes tuning x, y, and z-axis oscillators each with the inductance of their associated wound-core inductive sensor. The inductance is a function of the sensed first field strength, and further includes providing x, y, and z components of the first sensor signal from the x, y, and z-axis oscillators, respectively. Likewise, providing the second sensor signal includes tuning x, y, and z-axis oscillators each with the inductance of their associated wound-core inductive sensor. The inductance is a function of the sensed second field strength, and further includes providing x, y, and z components of the second sensor signal from the x, y, and z-axis oscillators, respectively.

[0029] In a further preferred embodiment, receiving the first and second sensor signals and providing the

differential signal includes determining the respective frequencies of the x, y, and z components of the first and second sensor signals. It further includes determining the differences between the first sensor signal x, y, and z component frequencies and the corresponding second sensor signal x, y, and z component frequencies, and then providing the differential signal equal to the magnitude and polarity of the differences.

[0030] In still another aspect of this invention, a method of verifying the location of a magnet associated with a medical tube within the body of a patient, comprising: sensing a first static magnetic field strength at a first distance from the magnet; sensing a second static magnetic field strength at a second distance from the magnet which is greater than the first distance; providing a first sensor signal which is a function of the first static magnetic field strength; providing a second sensor signal which is a function of the second static magnetic field strength; receiving the first and second sensor signals and providing a differential signal which is a function of the difference between the first static magnetic field strength and the second static magnetic field strength; receiving and indicating the polarity of the differential signal; and manipulating the magnet until the indicated polarity of the differential signal changes.

[0031] These and other features of the present invention will be better understood with reference to the following detailed description, appended claims and accompanying drawings.

Brief Description of the Drawings

[0032] Figures 1(a) and 1(b) are block diagrams illustrating the structure and operation of a representative detection apparatus of this invention.

[0033] Figure 2 is a block diagram illustrating an embodiment of the first and second sensor, as well as the sensor driver.

[0034] Figure 3 illustrates an embodiment of a detection apparatus of this invention.

[0035] Figure 4 illustrates the location of a magnet fixed to the end of a medical tube positioned within the body of a human patient using the detection apparatus of Figure 3.

[0036] Figure 5 illustrates the orientation of the x, y and z flux-gate sensors in an embodiment of a detection apparatus of this invention.

[0037] Figure 6 is a block diagram illustrating the structure and operation of a preferred embodiment of the detection apparatus of Figure 1(a).

[0038] Figure 7 is a block diagram illustrating a preferred embodiment of a detection apparatus of this invention comprising first and second sensors, first and second detectors , and a microprocessor.

Detailed Description of the Invention

[0039] The present invention provides an apparatus and method for detecting the location of a medical tube within the body of a patient. As used herein, the term "medical tube" means any type of tube or device which may be inserted into a patient's body, including (but not limited to) catheters, guide wires, and medical instruments. For example, catheters include such items as feeding tubes, urinary catheters, guide wires and dilating catheters, as well as nasogastric tubes, endotracheal tubes, stomach pump tubes, wound drain tubes, rectal tubes, vascular tubes, Sengstaken-Blakemore tubes, colonic decompression tubes, pH catheters, motility catheters, and urological tubes. Guide wires are often used to guide or place dilators and other medical tubes. Medical instruments include endoscopes and colonoscopes. In short, the location of any foreign object within a patient's body is a suitable device for detection by the present invention, and is encompassed within the term "medical tube".

[0040] The present invention detects the location of the medical tube by sensing the static magnetic field strength gradient produced by a permanent magnet associated with the medical tube. As used herein, the term "associated with" means permanently fixed, removably attached, or in close proximity to, the medical tube. In one embodiment, such as a feeding tube, the magnet is associated with the end of the medical tube. In another embodiment, such as a Sengstaken-Blakemore tube, the magnet is associated with the medical tube at a location above the gastric balloon. Preferably, the magnet is a small, cylindrical, rotatably attached, rare-earth magnet. Suitable magnets include rare earth magnets such as samarium cobalt and neodymium iron boron, both of which generate high field strengths per unit volume. While magnets which generate a high field strength for their size are preferred, weaker magnets such as Alnico or ceramic may also be utilized.

[0041] Since the magnet of this invention is permanent, it requires no power source. Accordingly, the magnet maintains its magnetic field indefinitely, which allows long-term positioning and detection of medical tubes without the disadvantages associated with an internal or external power source. In particular, by avoiding the use of a power source, the undesirable electrical connections necessary for the use of a power source are avoided. Thus, there is no risk of shock to (or possible electrocution of) the patient. Furthermore, the magnet's static magnetic field passes unattenuated through body tissue and bone. This property allows the use of the present invention to detect the medical tube at any location within the patient's body.

[0042] The magnet, and hence the medical tube, is detected using a detection apparatus which contains at least two static magnetic field strength sensors configured geometrically to null detection of ambient, homogeneous magnetic fields (e.g., the earth's field), while still detecting the magnetic field strength gradient produced by the magnet. The detection apparatus is an active, electronic instrument, and can detect the relatively

small magnetic field strength gradient produced by the magnet at distances ranging from several centimeters to several decimeters, and preferably from about 2 centimeters to about 3 decimeters. It also indicates the value of the gradient, thus allowing the user to accurately determine the location of the magnet, and hence the medical tube. In a preferred embodiment, the detection apparatus indicates the value of the gradient as both a magnitude and a polarity. By manipulating the magnet until the indicated polarity changes, detection of the location of the medical tube can be verified. Such manipulation of the magnet can be accomplished either by means of an attached guide wire, or by rotating the medical tube itself.

[0043] The static magnetic field strength sensors can detect the field strength as a scalar or, in a preferred embodiment, as a vector. In this preferred embodiment, the sensors each detect separate strength values in the orthogonal x, y, and z axes.

[0044] Due to the sensitivity of the apparatus of the present invention to the magnet's field strength gradient, additional imaging equipment is not necessary to detect the location of the medical tube. Accordingly, the present invention is suitable for use in environments which lack such equipment. For example, nursing homes rarely have X-ray equipment on-site, and the apparatus and method of the present invention is particularly suited for use in such facilities.

[0045] Referring to Figures 1(a) and 1(b), a block diagram illustrating the structure and operation of a representative detection apparatus of this invention is shown. In Figure 1(a), a static magnetic field strength sensor driver (30) provides a first static magnetic field strength sensor (10) and a second static magnetic field strength sensor (20) with a driver signal (31), thereby causing the first sensor (10) to provide a first sensor signal (11) and the second sensor (20) to provide a second sensor signal (21).

[0046] The first and second sensor signals (11) and (21) are functions of a first and second static magnetic field strength, respectively, sensed at a first and second distance, respectively, from the magnet. The first sensor (10) and the second sensor (20) are separated by a distance equal to the difference between the first and second distances. In this geometric configuration, while an ambient magnetic field strength (such as the earth's field strength) will have an equivalent value when sensed by either sensor (10) or (20), the magnet's magnetic field strength will have a different value depending on whether it is sensed by the first sensor (10) or the second sensor (20). By subtracting the field strength sensed at one sensor from the field strength sensed at the other, the magnet's field strength gradient can be sensed while at the same time nulling sensing of the earth's field strength. Several different types of sensors may be used in the practice of this invention, including (but not limited to) Hall-effect, flux-gate, wound-core inductive, squid, magneto-resistive, and nuclear precession sensors. In addition, a plurality of sensors may be employed.

[0047] In a preferred embodiment, the first sensor (10) and the second sensor (20) detect the first and second static magnetic field strengths, respectively, as vectors. In this embodiment the first and second sensor signals (11) and (21) are also vectors. This embodiment is discussed in more detail below with reference to Figures 5 and 6.

[0048] A first amplifier (12) receives the first sensor signal (11) and provides a first amplified signal (13) which is proportional to the first sensor signal (11). Similarly, a second amplifier (22) receives the second sensor signal (21) and provides a second amplified signal (23) which is proportional to the second sensor signal (21). In a preferred embodiment, the proportionality constant between the amplified signals (13) and (23) and the sensor signals (11) and (21) (i.e., the gain of the amplifiers (12) and (22)) will be variable, either automatically or manually, to maintain appropriate sensitivity as the detection apparatus approaches the magnet. In the preferred embodiment, the amplified signals (13) and (23) are vectors.

[0049] A first integrator (14) receives the first amplified signal (13) and provides a first detection signal (15), which is the integral of the first amplified signal (13). Likewise, a second integrator (24) receives the second amplified signal (23) and provides a second detection signal (25), which is the integral of the second amplified signal (23). Because the integrals of the amplified signals (13) and (23), and hence the sensor signals (11) and (21), are proportional to the sensed first and second field strengths, the detection signals (15) and (25) are proportional to the sensed first and second field strengths. In a preferred embodiment, the detection signals (15) and (25) are vectors.

[0050] A differential amplifier (40) receives the detection signals (15) and (25) and provides a differential signal (41) which is a function of the difference between the detection signals (15) and (25). In the absence of any sensed magnetic field strength gradient, the differential signal (41) from the differential amplifier (40) has a value of zero. When the detection apparatus is brought in close proximity to the magnet, the sensed value of the gradient between the sensors (10) and (20) is non-zero, and therefore the value of the differential signal (41) is non-zero. The polarity of the value (i.e., positive or negative) depends upon the orientation of the sensed magnet. In a preferred embodiment, the differential signal (41) is a vector, and the value of the differential signal includes the vector's magnitude and direction.

[0051] Referring to Figure 1(b), a magnitude circuit (60) receives the differential signal (41) and provides a magnitude signal (61) which is proportional to the magnitude of the differential signal (41). A visual display driver (62) then receives the magnitude signal (61) and provides visual display signals (64) to a visual display (66). In a preferred embodiment, the visual display (66) displays a continuous analog representation of the mag-

net's magnetic field strength gradient, including its magnitude and polarity. Such a representation can be made with a light-emitting diode bar array or a liquid crystal display. In addition, a speaker (67) may optionally be employed. A tone generator (63) receives the magnitude signal (61) and provides a tone signal (65) to the speaker (67). The tone signal (65) is a function of the magnitude signal (61). The sound projected by the speaker (67) may change in volume or pitch corresponding to the magnitude signal (61). Such a visual display (66) and/or speaker (67) allows the user to move or sweep the detection apparatus over the patient's body and to quickly determine the nearest external point to the location of the internal magnet associated with the medical tube.

[0052] In a further embodiment, an optional polarity circuit (70) receives the differential signal (41) and provides a polarity signal (71) which is a function of the polarity of the differential signal (41). In a preferred embodiment, the differential signal (41) is a vector, and the polarity of the differential signal is the direction of the vector. A polarity display driver (72) then receives the polarity signal (71) and provides a polarity display signal (73) to a polarity display (74). In this embodiment, the magnet is preferably made of neodymium iron boron (NdFeB), and is a small cylinder with dimensions on the order of 0.10 inches in diameter and 0.25 to 0.5 inches in length. The magnet is magnetized parallel to the diameter or transverse axis--that is, the north and south magnetic poles are half cylinders. This form of magnetization provides the greatest field strength at a given distance for such a cylindrical magnet. In addition, this magnet configuration allows the user to verify that the detection apparatus is sensing the magnet. Specifically, the user can rotate the magnet by, for example, manually rotating the medical tube. Such rotation about the longitudinal axis causes the sensed polarity to change. This change is indicated by the detection apparatus to the user. Alternatively, rather than rotating the medical tube, the magnet may be rotatably fixed to the medical tube such that the user may rotate the magnet by, for example, rotating a guide wire running down the medical tube and attached to the magnet.

[0053] Referring to Figures 1(a) and 1(b), an optional microprocessor (50) receives the amplified signals (13) and (23), and receives and provides control, monitoring, and calibration signals (51) from and to the sensor driver (30), the first and second amplifiers (12) and (22), the differential amplifier (40), and the visual display driver (62). It should be understood that the microprocessor (50) and its accompanying software may be the only digital element of an otherwise analog embodiment of the present invention, it may be an element in a mixed-mode embodiment, or it may be a digital element in a fully digital embodiment.

[0054] The apparatus of the present invention can detect the location of a wide variety of medical tubes. For example, a Sengstaken-Blakemore tube is sometimes inserted into the stomach and esophagus of a patient to stop bleeding from severe esophageal varices. Such a tube is a multilumen tube with a suction tube in the stomach to detect bleeding, a gastric balloon in the proximal stomach to act as an anchor to hold the tube in place and to press on varices at the junction between the esophagus and stomach, an esophageal balloon to press on the varices directly and stop the bleeding, and a suction tube above the esophageal balloon to remove saliva and blood. By placing a magnet between the esophageal and gastric balloons, the present invention may be used to detect the magnet, and hence the position of the medical tube within the patient. With existing technology, it is generally necessary to wait 20-30 minutes in order to obtain an x-ray to confirm the location of the gastric balloon. In the practice of this invention, once the magnet located on the tube between the esophageal and gastric balloons has been located in the stomach, the gastric balloon can be immediately inflated, thus substantially reducing the time and expense associated with existing x-ray localization of Sengstaken-Blakemore tubes.

[0055] In a further embodiment with respect to feeding tubes, the magnet may be incorporated into the tip of the tube. The weight of the magnet thus helps the tube be passed and advanced down the trachea and esophagus and into the stomach. In this embodiment, the size of the magnet should not exceed about 4-5 mm in diameter so that it can be passed into the stomach via either the nose or mouth. Once in place, the location of the magnet, and thus the end of the feeding tube, can be determined by the apparatus of the present invention. In an alternative embodiment, the magnet may be located at the end of a wire The magnet is then inserted into the feeding tube and pushed to the end of the tube by the wire. The feeding tube is then passed via the mouth or nose into the stomach. After the end of the feeding tube has been located at the desired position (i.e., by detection of the magnet at the end of the tube), the wire with the magnet attached is withdrawn from the feeding tube and either disposed of or sterilized. If a patient has a feeding tube placed every day, the same wire with magnet on the tip can be repeatedly used to locate the end of the feeding tube by the apparatus of this invention. Such a wire also serves to stiffen the feeding tube, making it easier to pass and advance.

[0056] Similarly, for several procedures in gastroenterology and other specialties, it is necessary to pass a guide wire into an organ. Once the guide wire is in place (usually with the assistance of an endoscope), another tube is passed over the guide wire. An example is esophageal stricture management. In this instance, there is a narrowing of the esophagus, and patients complain of trouble swallowing (dysphagia). A common technique used to dilate the stricture is to place a wire through the stricture and into the stomach, and then pass progressively larger dilators over the wire. The wire thus acts like a monorail or guide to keep the tip of the larger di-

lator catheter in the lumen. This reduces the chance of causing a perforation or hole in the esophagus. To ensure that the tip of the guide wire is in the stomach, x-ray verification is normally utilized.

[0057] In the practice of this invention, the location of such a guide wire may be confirmed by placing a magnet at or near the end of the guide wire. With regard to such esophageal stricture guide wires, the wire must be relatively stiff. Thus, a spring is normally located on the end of the wire in order to avoid perforating the esophagus, and the spring is sized such that it can pass down the channel of an endoscope (typically 2.5 to 3.5 mm in diameter). Thus, a small magnet may be located either above, below or within the spring of such guide wires. The guide wire and spring may then be inserted into the patient by passage down the channel of the endoscope. The present invention permits a physician to confirm that the tip of the guide wire remains in the stomach after the use of each progressively larger dilator.

[0058] This invention also permits the use of a guide wire having a spring tip/magnet end without the need for endoscope placement. Rather, the guide wire may be passed directly into stomach, and its location determined by the apparatus of this invention. The size limitations associated with the use of an endoscope (i.e., the 2.5-3.5 mm diameter channel) can thus be avoided, and larger guide wires or tubes having magnets located near the end can be employed. For example, a flexible tube of about 8 mm in diameter having a magnet located at the end can readily be passed into the stomach, and larger dilators passed over the flexible tube. In this embodiment, the need for a spring is obviated due to the use of the larger diameter flexible tube rather than the guide wire.

[0059] As a medical tube is inserted into a patient, the location of the magnet can be sensed by moving the detection apparatus over the surface of the patient's body and watching the visual display. As the sensors approach the magnet inside the patient, the display will indicate a greater magnitude, by increasing the height of the display bar graph, and by increasing the volume or pitch of the sound projected by the speaker. Also, after initial tube positioning, the location of the magnet can be similarly verified at any time. Furthermore, by monitoring variations in the static magnetic field arising from motion of the magnet fixed, removably attached, or in close proximity to the medical tube, such as rocking or displacement due to the distinct frequencies of endogenous contractions between stomach and proximal small bowel, the location of the magnet which is fixed, removably attached, or in close proximity to the medical tube can be distinguished between the stomach and proximal small bowel.

[0060] Although the present invention has been described in detail, with reference to certain preferred embodiments, other embodiments are possible. For example, one skilled in this art would understand that the invention may be implemented with analog, mixed-mode, or digital elements, and with either discrete components or integrated circuits, or both. Furthermore, the following specific examples are offered by way of illustration, not limitation.

EXAMPLES

Example 1

Detection Apparatus

[0061] In this representative embodiment, the detection apparatus includes a pair of flux-gate toroidal sensors, their sensor driver, amplifiers, integrators, a differential amplifier, a magnitude circuit, a visual display driver, a visual display, a tone generator, a speaker, a polarity circuit, a polarity display driver, and a polarity display.

[0062] Referring to Figure 3, each flux-gate toroidal sensor (81a) and (81b) comprises a 1 cm nickel-iron alloy toroid (10a) and (20a) with an excitation winding (10c) and (20c) and a detection winding (10b) and (20b). The excitation windings (10c) and (20c) are #37 gauge wire evenly wound in a toroidal manner around the perimeter of each toroid (10a) and (20a) such that the wire is closely spaced in a single layer. The detection windings (10b) and (20b) consist of #37 gauge wire closely wound around an outside diameter of each toroid (10a) and (20a). The flux-gate toroidal sensors (81a) and (81b) are fixed near each end of an 8 cm mounting arm (82), with their detection winding axes aligned and parallel to the length of the mounting arm.

[0063] Referring to Figures 1 through 3, the sensor driver (30) for each flux-gate toroidal sensor (81a) and (81b) comprises an oscillator (30a) and output transistors (30b), which are alternately switched by the oscillator, allowing current to flow through the excitation windings (10c) and (20c) in alternating directions at the oscillator frequency. The load of the output transistors is set to allow the current to drive each toroid into magnetic saturation at the peak current values in both directions. The amplifiers (12) and (22) and integrators (14) and (24) receive the voltage developed across their respective detection windings (10b) and (20b) when the toroid is driven into and out of saturation, and then provide an integrated voltage which is proportional to any external static magnetic field flux passing through the toroid on an axis parallel to the winding axis of the detection windings. The amplifiers (12) and (22) are biased to remain within their dynamic range during operation of the detection apparatus, and to account for slight variations in the flux-gate toroidal sensors (81a) and (81b).

[0064] The differential amplifier (40) amplifies the difference between the integrated voltages from the integrators. The magnitude circuit (60) provides a voltage proportional to the magnitude of this difference voltage, and a polarity voltage coding the polarity of the difference voltage.

[0065] The visual display driver (62) includes an integrated circuit which drives a visual display (66), such as a 10-step light emitting diode bar array, depending on its input voltage. A polarity circuit (70) and a polarity display driver (72) drive one of two light emitting diodes (74a) and (74b), depending on the polarity voltage. A voltage-controlled oscillator chip generates a speaker-projected sound whose pitch is proportional to the input voltage. The 10-step bar array displays the magnitude of the magnetic field gradient detected by the flux-gate toroidal sensors, while one of the two light emitting diodes lights up to indicate the polarity of the gradient.

Example 2

Detection of a Feeding Tube

[0066] Referring to Figure 4, a feeding tube (90), with a permanent magnet (91) located in its tip, includes an elongated, tubular, main portion with a sealed magnet chamber at its distal end, and an adapter at its proximal end to allow connection to a source of feeding formula. Side apertures at the distal end, above the magnet chamber, extend from the inner tube lumen to the exterior of the tube allowing the feeding formula to reach the patient's stomach. The sealed magnet chamber contains a cylindrical, rare earth, permanent magnet (91), of approximate size 0.10 inches diameter by 0.50 inches in length. The chamber is fused to the distal end of the feeding tube with its long axis parallel to the long axis of the feeding tube. The feeding tube and magnet chamber are composed of a flexible polymer which is chemically, biologically, and mechanically appropriate for purposes of gastroenteric feeding.

[0067] The feeding tube (90) is inserted into a patient's nose, down the esophagus and into the stomach. The detection apparatus (80) described in Example 1 above and illustrated in Figure 3, is used to sense the magnet's static magnetic field strength (91a) at two different distances (91b) and (91c) while immersed in the earth's ambient magnetic field (100). As the detection apparatus (80) is moved about the patient's body, greater and lesser magnetic field gradients are indicated. The feeding tube (90) is located by moving the detection apparatus until the greatest magnitude is indicated by detection apparatus (80).

Example 3

Detection Apparatus

[0068] Referring to Figure 5, in a preferred alternative embodiment of the apparatus of Example 1, the first sensor (10) includes x, y, and z-axis sensors (101), (102), and (103), respectively, while the second sensor (20) includes x, y, and z-axis sensors (201), (202), and (203), respectively. In this embodiment the sensors are flux-gate toroidal sensors with an associated sensor driver (not shown).

[0069] Referring to Figure 6, the first and second sensor signals (11) and (21), the first and second amplified signals (13) and (23), the first and second detection signals (15) and (25), and the differential signal (41) are vectors.

[0070] The first amplifier (12) includes x, y, and z-axis amplifiers (121), (122) and (123). Similarly, the second amplifier includes x, y, and z-axis amplifiers (221), (222) and (223). In addition, the first integrator (14) includes x, y, and z-axis integrators (141), (142) and (143), while the second integrator includes x, y, and z-axis integrators (241), (242) and (243). Finally, the differential amplifier (40) includes x, y, and z-axis differential amplifiers (401), (402) and (403).

[0071] The operation of the first and second sensors (10) and (20), the first and second amplifiers (12) and (22), the first and second integrators (14) and (24), and the differential amplifier (4), is the same as in Example 1, with the exception that in this preferred embodiment, the signals (11), (21), (13), (23), (15), (25), and (41) are vectors.

Example 4

Detection Apparatus with Wound-Core Inductive Sensors

[0072] As noted above, the invention may be implemented with analog, mixed-mode, or digital elements. In a preferred embodiment, the detection apparatus detects the static magnetic field strength gradient as a vector, as opposed to a scalar.

[0073] Referring to Figure 7, a representative embodiment includes a first and second sensor (10) and (20), a first and second detector (207) and (206), and a microprocessor (208).

[0074] The first sensor (10) includes an x, y, and z-axis oscillator (226), (227) and (228) having associated wound-core inductive sensors (226a), (227a) and (228a), respectively. Similarly, the second sensor (20) includes an x, y, and z-axis oscillator (216), (217) and (218) having wound-core inductive sensors (216a), (217a) and (218a), respectively. Further, the first detector (207) includes an x, y, and z-axis frequency counter (246), (247) and (248), while the second detector (206) includes an x, y, and z-axis frequency counter (236), (237) and (238).

[0075] The first and second sensor signals (11) and (21), the first and second detection signals (15) and (25), and the differential signal (41) are vectors. The first sensor x, y, and z-axis oscillators provide the x, y, and z components, respectively, of the first sensor signal (11). Similarly, the first detector x, y, and z-axis frequency counters provide the x, y, and z components, respectively, of the first detection signal (15). Likewise, the second sensor x, y, and z-axis oscillators provide the x, y, and z components, respectively, of the second sensor

signal (21), and the second detector x, y, and z-axis frequency counters provide the x, y, and z components, respectively, of the second detection signal (25).

[0076] The wound-core inductive sensors (216a), (217a), (218a), (226a), (227a), and (228a) are high-permeability magnetic cores wrapped with windings. Each wound-core inductive sensor, together with its associated oscillator, comprises an LR relaxation oscillator having a period fixed by the inductance L of the sensor. Since the inductance L of each sensor is a function of the static magnetic field strength sensed by that sensor, the period of the associated oscillator is a function of the same static magnetic field strength.

[0077] Thus, the x, y, and z-axis frequency counters (246), (247) and (248) receive the x, y, and z components, respectively, of the first sensor signal (11), and the period of these components is a function of the first static magnetic field strength. Similarly, the x, y, and z-axis frequency counters (236), (237) and (238) receive the x, y, and z components, respectively, of the second sensor signal (21), and the period of these components is a function of the second static magnetic field strength.

[0078] Each frequency counter determines the frequency of its associated first or second signal component. It then provides that frequency to the microprocessor (208) in the form of the first and second detection signals (15) and (25). The microprocessor (208) determines the magnitude of the detection signals (15) and (25) by subtracting the second detection signal vector from the first detection signal vector, summing the squares of the components of the resulting difference vector, and taking the square root of the resulting sum. The microprocessor then provides the differential signal (41) to the magnitude circuit.

[0079] From the foregoing, it will be appreciated that, although specific embodiments of this invention have been described herein for purposes of illustration, various modifications may be made without deviating from the scope of the invention. Accordingly, the invention is not limited except by the appended claims.

Claims

1. A system for detecting the location of a magnet associated with a medical tube within the body of a patient in the presence of the Earth's magnetic field, the system comprising
   a magnet (91) associated with a medical tube (90) to be, in operation, inserted into the body of a patient and a detector, the detector (80) comprising:

   means for sensing a first static magnetic field strength (10) and providing a first sensor signal which is a function of the first static magnetic field strength;
   means for sensing a second static magnetic field strength (20) and providing a second sensor signal which is a function of the second static magnetic field strength, wherein the means for sensing the first static magnetic field strength (10) and the means for sensing the second static magnetic field strength (20) are separated by a predetermined distance;
   means for receiving the first sensor signal (12,14) and providing a first detection signal which is a function of the first sensor signal;
   means for receiving the second sensor signal (22,24) and providing a second detection signal which is a function of the second sensor signal;
   means for receiving the first and second detection signals (40) and providing a differential signal which is a function of the difference between the first detection signal and the second detection signal; and
   means for receiving and indicating a value (62,63,72) for the differential signal.

2. The system of claim 1, wherein the means for sensing the first static magnetic field strength (10) and providing the first sensor signal, and the means for sensing the second static magnetic field strength (20) and providing the second sensor signal, comprise:

   a static magnetic field strength sensor driver (30) for providing a driver signal; a first static magnetic field strength sensor (10) for receiving the driver signal and thereby providing the first sensor signal; and
   a second static magnetic field strength sensor (20) for receiving the driver signal and thereby providing the second sensor signal.

3. The system of claim 2, wherein the static magnetic field strength sensor driver (30) comprises an oscillator (30a) and output transistors (30b) which are alternately switchable by the oscillator and thereby provide the driver signal, wherein the first static magnetic field strength sensor (10) comprises a first flux-gate toroidal sensor (81a) which includes a first excitation winding (10c) for receiving the driver signal and a first detection winding (10b) for providing the first sensor signal, and wherein the second static magnetic field strength sensor (20) comprises a second flux-gate toroidal sensor (81b) which includes a second excitation winding (20c) for receiving the driver signal and a second detection winding (20b) for providing the second sensor signal.

4. The system of any preceding claim, wherein the means for receiving the first sensor signal (12,14) and providing the first detection signal comprises a first amplifier (12) for receiving the first sensor signal and providing a first amplified signal which is proportional to the first sensor signal, and a first in-

tegrator (14) for receiving the first amplified signal and providing the first detection signal, and wherein the means for receiving the second sensor signal (22,24) and providing the second detection signal comprises a second amplifier (22) for receiving the second sensor signal and providing a second amplified signal which is proportional to the second sensor signal, and a second integrator (24) for receiving the second amplified signal and providing the second detection signal.

5. The system of any preceding claim, wherein the means for receiving and indicating a value (62,63,72) for the differential signal comprises a magnitude circuit (60) for receiving the differential signal and providing a magnitude signal which is proportional to the magnitude of the differential signal, a visual display driver (62) for receiving the magnitude signal and providing a visual display signal, and a visual display (66) for receiving and visually indicating the visual display signal.

6. The system of claim 5, wherein the visual display driver (62) comprises a light emitting diode bar array driver, and the visual display (66) comprises a light emitting diode bar array.

7. The system of claim 5, wherein the means for receiving and indicating a value (62,63,72) for the differential signal further comprises a tone generator (63) for receiving the magnitude signal and providing a tone signal which is a function of the magnitude signal, and a speaker (67) for receiving and audibly indicating the tone signal.

8. The system of claim 5, wherein the means for receiving and indicating a value (62,63,72) for the differential signal further comprises a polarity circuit (70) for receiving the differential signal and providing a polarity signal which is a function of the polarity of the differential signal, a polarity display driver (72) for receiving the polarity signal and providing a polarity display signal, and a polarity display (74) for receiving and visually indicating the polarity display signal.

9. The system of any preceding claim, further comprising a means for automatically controlling, monitoring and calibrating the means for sensing the first static magnetic field strength (10) and providing the first sensor signal, the means for sensing the second static magnetic field strength (20) and providing the second sensor signal, the means for receiving the first sensor signal (12,14) and providing the first detection signal, the means for receiving the second sensor signal (22,24) and providing the second detection signal, the means for receiving the first and second detection signals and providing signal the differential, and the means for receiving and indicating a value (62,63,72) for the differential signal.

10. The system of claim 9, wherein the automatic controlling, monitoring, and calibrating means comprises a microprocessor (50).

11. The system of any preceding claim, wherein the driver signal, the first and second sensor signals, the first and second detection signals, and the differential signal are vectors.

12. The system of Claim 11, wherein the means for sensing the first static magnetic field strength (10) comprises:

an x-axis oscillator (226) which provides an x component of the first sensor signal, wherein the x-axis oscillator comprises a wound-core inductive sensor (226a), wherein the x component is a function of the inductance of the sensor (226a), wherein the inductance of the sensor (226a) is a function of the first static magnetic field strength;
a y-axis oscillator (227) which provides a y component of the first sensor signal, wherein the y-axis oscillator comprises a wound-core inductive sensor (227a), wherein the y component is a function of the inductance of the sensor (227a), wherein the inductance of the sensor (227a) is a function of the first static magnetic field strength; and
a z-axis oscillator (228) which provides a z component of the first sensor signal, wherein the z-axis oscillator comprises a wound-core inductive sensor (228a), wherein the z component is a function of the inductance of the sensor (228a), wherein the inductance of the sensor (228a) is a function of the first static magnetic field strength;

and wherein the means for sensing the second static magnetic field strength (20) comprises:

an x-axis oscillator (216) which provides an x component of the second sensor signal, wherein the x-axis oscillator comprises a wound-core inductive sensor (216a), wherein the x component is a function of the inductance of the sensor (216a), wherein the inductance of the sensor (216a) is a function of the second static magnetic field strength;
a y-axis oscillator (217) which provides a y component of the second sensor signal, wherein the y-axis oscillator comprises a wound-core inductive sensor (217a), wherein the y component is a function of the inductance of the sensor (217a), wherein the inductance of the sen-

sor (217a) is a function of the second static magnetic field strength; and
a z-axis oscillator (218) which provides a z component of the second sensor signal, wherein the z-axis oscillator comprises a wound-core inductive sensor (218a), wherein the z component is a function of the inductance of the sensor (218a), wherein the inductance of the sensor (218a) is a function of the second static magnetic field strength.

13. The system of any one of Claims 11 to 12, wherein the means for receiving the first sensor signal comprises:

an x-axis frequency counter (246) which receives an x component of the first sensor signal and provides an x component of the first detection signal;
a y-axis frequency counter (247) which receives a y component of the first sensor signal and provides a y component of the first detection signal; and
a z-axis frequency counter (248) which receives a z component of the first sensor signal and provides a z component of the first detection signal; and
wherein the means for receiving the second sensor signal comprises: an x-axis frequency counter (236) which receives an x component of the second sensor signal and provides an x component of the second detection signal;
a y-axis frequency counter (237) which receives a y component of the second sensor signal and provides a y component of the second detection signal; and
a z-axis frequency counter (238) which receives a z component of the second sensor signal and provides a z component of the second detection signal.

14. A system according to any preceding claim, wherein the means for receiving the first and second detection signals and providing the differential signal comprises a differential amplifier.

15. A method of detecting the location of a magnet (91) associated with a medical tube (90) within the body of a patient, comprising:

sensing a first static magnetic field strength at a first distance from the magnet (91);
sensing a second static magnetic field strength at a second distance from the magnet which is greater than the first distance;
providing a first sensor signal which is a function of the first static magnetic field strength;
providing a second sensor signal which is a function of the second static magnetic field strength;
receiving the first and second sensor signals and providing a differential signal which is a function of the difference between the first static magnetic field strength and the second static magnetic field strength;
receiving and indicating a value for the differential signal; and
determining the location of the medical tube (90) by varying the first and second distances until the greatest value for the differential signal is indicated.

16. The method of claim 15, wherein the first sensor signal, the second sensor signal, and the differential signal are vectors.

17. The method of claim 15 or 16, wherein providing the first sensor signal comprises:

tuning an x-axis oscillator (226) with the inductance of an associated wound-core inductive sensor (226a), wherein the inductance is a function of the sensed first field strength and providing an x component of the first sensor signal from the x-axis oscillator (226);
tuning a y-axis oscillator (227) with the inductance of an associated wound-core inductive sensor (227a), wherein the inductance is a function of the sensed first field strength and providing a y component of the first sensor signal from the y-axis oscillator (227); and
tuning a z-axis oscillator (228) with the inductance of an associated wound-core inductive sensor (228a), wherein the inductance is a function of the sensed first field strength and providing a z component of the first sensor signal from the z-axis oscillator (228); and wherein providing the second sensor signal comprises:
tuning an x-axis oscillator (216) with the inductance of an associated wound-core inductive sensor (216a), wherein the inductance is a function of the sensed second field strength and providing an x component of the second sensor signal from the x-axis oscillator (216),
tuning a y-axis oscillator (217) with the inductance of an associated wound-core inductive sensor (217a), wherein the inductance is a function of the sensed second field strength and providing a y component of the second sensor signal from the y-axis oscillator (217), and
tuning a z-axis oscillator (218) with the inductance of an associated wound-core inductive sensor (218a), wherein the inductance is a function of the sensed second field, strength and providing a z component of the second

sensor signal from the z-axis oscillator (218).

18. The method of any one of Claims 15 to 17, wherein receiving the first and second sensor signals and providing the differential signal comprises:

determining the respective frequencies of an x, y, and z component of the first sensor signal;
determining the respective frequencies of an x, y, and z component of the second sensor signal;
determining the differences between the first sensor signal x, y, and z component frequencies and the corresponding second sensor signal x, y, and z component frequencies; and
providing the differential signal equal to a magnitude and polarity of the differences.

19. The method of any one of Claims 15 to 18, further comprising monitoring variations in the first and second static magnetic field strengths to verify the location of the medical tube.

20. A method of verifying the location of a magnet (91) associated with a medical tube (90) within the body of a patient, comprising:

sensing a first static magnetic field strength at a first distance from the magnet (91);
sensing a second static magnetic field strength at a second distance from the magnet (91) which is greater than the first distance;
providing a first sensor signal which is a function of the first static magnetic field strength;
providing a second sensor signal which is a function of the second static magnetic field strength;
receiving the first and second sensor signals and providing a differential signal which is a function of the difference between the first static magnetic field strength and the second static magnetic field strength;
receiving and indicating the polarity of the differential signal; and manipulating the magnet (91) until the indicated polarity of the differential signal changes.

21. The method of claim 20, wherein the magnet (91) is manipulated by rotation thereof.

22. The method of claim 20 or 21, further comprising monitoring variations in the first and second static magnetic field strengths to further verify the location of the medical tube (90).

Patentansprüche

1. System zum Erfassen der Position eines Magneten, der zu einer medizinischen Röhre in dem Körper eines Patienten gehört, in der Anwesenheit des Magnetfelds der Erde, mit folgenden Merkmalen:
ein Magnet (91), der zu einer medizinischen Röhre (90) gehört, die in den Körper eines Patienten eingeführt werden soll, die im Betrieb in den Körper eines Patienten eingeführt werden soll, und ein Detektor (80) mit folgenden Merkmalen:

Mittel zum Erfassen einer ersten statischen Magnetfeldstärke (10) und Vorsehen eines ersten Sensorsignals, das eine Funktion der ersten statischen Magnetfeldstärke ist;

Mittel zum Erfassen einer zweiten statischen Magnetfeldstärke (20) und Vorsehen eines zweiten Sensorsignals, das eine Funktion der zweiten statischen Magnetfeldstärke ist, wobei die Mittel zum Erfassen der ersten statischen Magnetfeldstärke (10) und die Mittel zum Erfassen der zweiten statischen Magnetfeldstärke (20) einen vorgegebenen Abstand zueinander aufweisen;

Mittel zum Empfangen des ersten Sensorsignals (12, 14) und Vorsehen eines ersten Erfassungssignals, das eine Funktion des ersten Sensorsignals ist;

Mittel zum Empfangen des zweiten Sensorsignals (22, 24) und Vorsehen eines zweiten Erfassungssignals, das eine Funktion des zweiten Sensorsignals ist;

Mittel zum Empfangen des ersten und des zweiten Erfassungssignals (40) und Vorsehen eines Differenzsignals, das eine Funktion der Differenz zwischen dem ersten Erfassungssignal und dem zweiten Erfassungssignal ist; und

Mittel zum Empfangen und Anzeigen eines Wertes (62, 63, 72) für das Differenzsignal.

2. System nach Anspruch 1, bei dem die Mittel zum Erfassen der ersten statischen Magnetfeldstärke (10) und Vorsehen des ersten Sensorsignals und die Mittel zum Erfassen der zweiten statischen Magnetfeldstärke (20) und Vorsehen des zweiten Sensorsignals folgende Merkmale aufweisen:

ein Sensortreiber (30) für eine statische Magnetfeldstärke zum Vorsehen eines Treibersignals; ein Sensor(10) für die erste statische Magnetfeldstärke zum Empfangen des Treiber-

signals und dadurch Vorsehen des ersten Sensorsignals; und ein Sensor (20) für die zweite statische Magnetfeldstärke zum Empfangen des Treibersignals und dadurch Vorsehen des zweiten Sensorsignals.

3. System nach Anspruch 2, bei dem der Sensortreiber (30) für die statische Magnetfeldstärke einen Oszillator (30a) und Ausgangstransistoren (30b) aufweist, die durch den Oszillator abwechselnd schaltbar sind und dadurch das Treibersignal vorsehen, wobei der Sensor (10) für die erste statische Magnetfeldstärke einen ersten Fluxgate-Ringsensor (81a) aufweist, der eine erste Erregerwicklung (10c) zum Empfangen des Treibersignals und eine erste Detektorwicklung (10b) zum Vorsehen des ersten Sensorsignals aufweist, und wobei der Sensor (20) für die zweite statische Magnetfeldstärke einen zweiten Fluxgate-Ringsensor (81b) aufweist, der eine zweite Erregerwicklung (20c) zum Empfangen des Treibersignals und eine zweite Detektorwicklung (20b) zum Vorsehen des zweiten Sensorsignals aufweist.

4. System nach einem der vorangehenden Ansprüche, bei dem die Mittel zum Empfangen des ersten Sensorsignals (12, 14) zum Vorsehen des ersten Erfassungssignals einen ersten Verstärker (12) zum Empfangen des ersten Sensorsignals und Vorsehen eines ersten verstärkten Signals, das proportional zu dem ersten Sensorsignal ist, und einen ersten Integrator (14) zum Empfangen des ersten verstärkten Signals und Vorsehen des ersten Erfassungssignals aufweisen, und die Mittel zum Empfangen des zweiten Sensorsignals (22, 24) und Vorsehen des zweiten Erfassungssignals einen zweiten Verstärker (22) zum Empfangen des zweiten Sensorsignals und Vorsehen eines zweiten Verstärkersignals, das proportional zu dem zweiten Sensorsignal ist, und einen zweiten Integrator (24) zum Empfangen des zweiten verstärkten Signals und Vorsehen des zweiten Erfassungssignals aufweisen.

5. System nach einem der vorangehenden Ansprüche, bei dem die Mittel zum Empfangen und Anzeigen eines Wertes (62, 63, 72) fiir das Differenzsignal einen Betragsschaltkreis (60) zum Empfangen des Differenzsignals und Vorsehen eines Betragssignals, das proportional zum Betrag des Differenzsignals ist, einen optischen Anzeigetreiber (62) zum Empfangen des Betragssignals und Vorsehen eines optischen Anzeigesignals, und eine optische Anzeige (66) zum Empfangen und optischen Anzeigen des optischen Anzeigesignals aufweisen.

6. System nach Anspruch 5, bei dem der optische Anzeigetreiber (62) ein Treiber einer Balkenanordnung aus lichtemittierenden Dioden umfaßt und die optische Anzeige (66) eine Balkenanordnung aus lichtemittierenden Dioden umfaßt.

7. System nach Anspruch 5, bei dem die Mittel zum Empfangen und Anzeigen eines Wertes (62, 63, 72) für das Differenzsignal einen Tongenerator (63) zum Empfangen des Betragssignals und Vorsehen eines Tonsignals, das eine Funktion des Betragssignals ist, und einen Lautsprecher (67) zum Empfangen und hörbaren Wiedergeben des Tonsignals umfassen.

8. System nach Anspruch 5, bei dem die Mittel zum Empfangen und Anzeigen eines Wertes (62, 63, 72) für das Differenzsignal einen Polaritätsschaltkreis (70) zum Empfangen des Differenzsignals und Vorsehen eines Polaritätssignals, das eine Funktion der Polarität des Differenzsignals ist, einen Polaritätsanzeigetreiber (72) zum Empfangen des Polaritätssignals und Vorsehen eines Polaritätsanzeigesignals und eine Polaritätsanzeige (74) zum Empfangen und optischen Anzeigen des Polaritätsanzeigesignals umfassen.

9. System nach einem der vorangehenden Ansprüche, mit einer Einrichtung zum automatischen Steuern, Überwachen und Eichen der Mittel zum Erfassen der ersten statischen Magnetfeldstärke (10) und Vorsehen des ersten Sensorsignals, der Mittel zum Erfassen der zweiten statischen Magnetfeldstärke (20) und Vorsehen des zweiten Sensorsignals, der Mittel zum Empfangen des ersten Sensorsignals (12, 14) und Vorsehen des ersten Erfassungssignals, der Mittel zum Erfassen des zweiten Sensorsignals (22, 24) und Vorsehen des zweiten Erfassungssignals, der Mittel zum Empfangen des ersten und des zweiten Erfassungssignals und Vorsehen des Differenzsignals und der Mittel zum Empfangen und Anzeigen eines Wertes (62, 63, 72) für das Differenzsignal aufweist.

10. System nach Anspruch 9, bei dem die Einrichtung zum automatischen Steuern, Überwachen und Eichen einen Mikroprozessor (50) umfaßt.

11. System nach einem der vorangehenden Ansprüche, bei dem das Treibersignal, das erste und das zweite Sensorsignal, das erste und das zweite Erfassungssignal und das Differentialsignal Vektoren sind.

12. System nach Anspruch 11, bei dem die Mittel zum Erfassen der ersten statischen Magnetfeldstärke (10) folgende Merkmale aufweisen:

ein x-Achsen-Oszillator (226), der eine x-Komponente des ersten Sensorsignals vorsieht,

wobei der x-Achsen-Oszillator einen induktiven Wickelkemsensor (226a) aufweist, wobei die x-Komponente eine Funktion der Induktivität des Sensors (226a) ist, wobei die Induktivität des Sensors (226a) eine Funktion der ersten statischen Magnetfeldstärke ist;

ein y-Achsen-Oszillator (227) der eine y-Komponente des ersten Sensorsignals vorsieht, wobei der y-Achsen-Oszillator einen induktiven Wickelkemsensor (227a) aufweist, wobei die y-Komponente eine Funktion der Induktivität des Sensors (227a) ist, wobei die Induktivität des Sensors (227a) eine Funktion der ersten statischen Magnetfeldstärke ist; und

ein z-Achsen-Oszillator (228) der eine z-Komponente des ersten Sensorsignals vorsieht, wobei der z-Achsen-Oszillator einen induktiven Wickelkemsensor (228a) aufweist, wobei die z-Komponente eine Funktion der Induktivität des Sensors (228a) ist, wobei die Induktivität des Sensors (228a) eine Funktion der ersten statischen Magnetfeldstärke ist;

und wobei die Mittel zum Erfassen der zweiten statischen Magnetfeldstärke (20) folgende Merkmale aufweisen:

ein x-Achsen-Oszillator (216), der eine x-Komponente des ersten Sensorsignals vorsieht, wobei der x-Achsen-Oszillator einen induktiven Wickelkemsensor (216a) aufweist, wobei die x-Komponente eine Funktion der Induktivität des Sensors (216a) ist, wobei die Induktivität des Sensors (216a) eine Funktion der zweiten statischen Magnetfeldstärke ist;

ein y-Achsen-Oszillator (217) der eine y-Komponente des ersten Sensorsignals vorsieht, wobei der y-Achsen-Oszillator einen induktiven Wickelkemsensor (217a) aufweist, wobei die y-Komponente eine Funktion der Induktivität des Sensors (217a) ist, wobei die Induktivität des Sensors (217a) eine Funktion der zweiten statischen Magnetfeldstärke ist; und

ein z-Achsen-Oszillator (218) der eine z-Komponente des ersten Sensorsignals vorsieht, wobei der z-Achsen-Oszillator einen induktiven Wickelkemsensor (218a) aufweist, wobei die z-Komponente eine Funktion der Induktivität des Sensors (218a) ist, wobei die Induktivität des Sensors (218a) eine Funktion der zweiten statischen Magnetfeldstärke ist.

13. System nach einem der Ansprüche 11 bis 12, bei dem die Mittel zum Empfangen des ersten Sensorsignals folgende Merkmale aufweisen:

ein x-Achsen-Frequenzzähler (246), der eine x-Komponente des ersten Sensorsignals empfängt und eine x-Komponente des ersten Erfassungssignals vorsieht;

ein y-Achsen-Frequenzzähler (247), der eine y-Komponente des ersten Sensorsignals empfängt und eine y-Komponente des ersten Erfassungssignals vorsieht; und

ein z-Achsen-Frequenzzähler (248), der eine z-Komponente des ersten Sensorsignals empfängt und eine z-Komponente des ersten Erfassungssignals vorsieht; und

wobei die Mittel zum Empfangen des zweiten Sensorsignals folgende Merkmale aufweisen:

ein x-Achsen-Frequenzzähler (236), der eine x-Komponente des zweiten Sensorsignals empfängt und eine x-Komponente des zweiten Erfassungssignals vorsieht;

ein y-Achsen-Frequenzzähler (237), der eine y-Komponente des zweiten Sensorsignals empfängt und eine y-Komponente des zweiten Erfassungssignals vorsieht; und

ein z-Achsen-Frequenzzähler (238), der eine z-Komponente des zweiten Sensorsignals empfängt und eine z-Komponente des zweiten Erfassungssignals vorsieht.

14. System nach einem der vorangehenden Ansprüche, bei dem die Mittel zum Empfangen des ersten und des zweiten Erfassungssignals und Vorsehen des Differenzsignals einen Differenzverstärker umfassen.

15. Verfahren zum Erfassen der Position eines Magneten (91), der zu einer medizinischen Röhre (90) in dem Körper eines Patienten gehört, mit folgenden Verfahrensschritten:

Erfassen einer ersten statischen Magnetfeldstärke bei einem ersten Abstand von dem Magneten (91);

Erfassen einer zweiten statischen Magnetfeldstärke bei einem zweiten Abstand von dem Magneten, der größer als der erste Abstand ist;

Vorsehen eines ersten Sensorsignals, das eine Funktion der ersten statischen Magnetfeldstärke ist;

Vorsehen eines zweiten Sensorsignals, das eine Funktion der zweiten statischen Magnetfeldstärke ist;

Empfangen des ersten und des zweiten Sensorsignals und Vorsehen eines Differenzsignals, das eine Funktion der Differenz zwischen der ersten statischen Magnetfeldstärke und der zweiten statischen Magnetfeldstärke ist;

Empfangen und Anzeigen eines Wertes für das Differenzsignals; und

Ermitteln der Position der medizinischen Röhre (90) durch Variieren des ersten und des zweiten Abstandes, bis der größte Wert für das Differenzsignal angegeben wird.

16. Verfahren nach Anspruch 15, bei dem das erste Sensorsignal, das zweite Sensorsignal und das Differenzsignal Vektoren sind.

17. Verfahren nach Anspruch 15 oder 16, bei dem das Vorsehen des ersten Sensorsignals folgende Schritte umfaßt:

Abstimmen eines x-Achsen-Oszillators (226) mit der Induktivität eines zugehörigen induktiven Wickelkernsensors (226a), wobei die Induktivität eine Funktion der erfaßten erste Feldstärke ist, und Vorsehen einer x-Komponente des ersten Sensorsignals durch den x-Achsen-Oszillator (226);

Abstimmen eines y-Achsen-Oszillators (227) mit der Induktivität eines zugehörigen induktiven Wickelkernsensors (227a), wobei die Induktivität eine Funktion der erfaßten erste Feldstärke ist, und Vorsehen einer y-Komponente des ersten Sensorsignals durch den y-Achsen-Oszillator (227); und

Abstimmen eines z-Achsen-Oszillators (228) mit der Induktivität eines zugehörigen induktiven Wickelkernsensors (228a), wobei die Induktivität eine Funktion der erfaßten erste Feldstärke ist, und Vorsehen einer z-Komponente des ersten Sensorsignals durch den z-Achsen-Oszillator (228); und

wobei das Vorsehen des zweiten Sensorsignals folgende Verfahrensschritte umfaßt:

Abstimmen eines x-Achsen-Oszillators (216) mit der Induktivität eines zugehörigen induktiven Wickelkernsensors (216a), wobei die Induktivität eine Funktion der erfaßten zweiten Feldstärke ist, und Vorsehen einer x-Komponente des zweiten Sensorsignals durch den x-Achsen-Oszillator (216);

Abstimmen eines y-Achsen-Oszillators (217) mit der Induktivität eines zugehörigen induktiven Wickelkernsensors (217a), wobei die Induktivität eine Funktion der erfaßten zweiten Feldstärke ist, und Vorsehen einer y-Komponente des zweiten Sensorsignals durch den y-Achsen-Oszillator (217);

Abstimmen eines z-Achsen-Oszillators (218) mit der Induktivität eines zugehörigen induktiven Wickelkernsensors (218a), wobei die Induktivität eine Funktion der erfaßten zweiten Feldstärke ist, und Vorsehen einer z-Komponente des zweiten Sensorsignals durch den z-Achsen-Oszillator (218).

18. Verfahren nach einem der Ansprüche 15 bis 17, bei dem das Empfangen des ersten und des zweiten Sensorsignals und das Vorsehen des Differenzsignals folgende Schritte umfaßt:

Ermitteln der jeweiligen Frequenzen einer x-, y- und z-Komponente des ersten Sensorsignals;

Ermitteln der jeweiligen Frequenzen einer x-, y- und z-Komponente des zweiten Sensorsignals;

Ermitteln der Differenzen zwischen dem x-, y- und z-Komponentenfrequenzen des ersten Sensorsignals und den entsprechenden x-, y- und z-Komponentenfrequenzen des zweiten Sensorsignals; und

Vorsehen des Differenzsignals entsprechend dem Betrag und der Polarität der Differenzen.

19. Verfahren nach einem der Ansprüche 15 bis 18, bei dem Veränderungen der ersten und der zweiten statischen Magnetfeldstärke überwacht werden, um die Position der medizinischen Röhre verifizieren.

20. Verfahren zum Verifizieren der Position eines Magneten (91), der zu einer medizinischen Röhre (90) in den Körper eines Patienten gehört, mit folgenden Verfahrensschritten:

Erfassen einer ersten statischen Magnetfeldstärke bei einem ersten Abstand von dem Magneten (91);

Erfassen einer zweiten statischen Magnetfeldstärke bei einem zweiten Abstand von dem Magneten (91), der größer als der erste Abstand

ist;

Vorsehen eines ersten Sensorsignals, das eine Funktion der ersten statischen Magnetfeldstärke ist;

Vorsehen eines zweiten Sensorsignals, das eine Funktion der zweiten statischen Magnetfeldstärke ist;

Empfangen des ersten und des zweiten Sensorsignals und Vorsehen eines Differenzsignals, das eine Funktion der Differenz zwischen der ersten statischen Magnetfeldstärke und der zweiten statischen Magnetfeldstärke ist;

Empfangen und Anzeigen der Polarität des Differenzsignals; und

Manipulieren des Magneten (91), bis sich die angezeigte Polarität des Differenzsignals ändert.

21. Verfahren nach Anspruch 20, bei dem der Magnet (91) durch Drehung des Magneten manipuliert wird.

22. Verfahren nach Anspruch 20 oder 21, bei dem Veränderungen der ersten und der zweiten statischen Magnetfeldstärke überwacht werden, um die Position der medizinischen Röhre weiter verifizieren.

Revendications

1. Système pour détecter l'emplacement d'un aimant associé à un tube médical dans le corps d'un patient en présence du champ magnétique terrestre, le système comportant

un aimant (91) associé à un tube médical (90) destiné, en fonctionnement, à être inséré dans le corps d'un patient et un détecteur, le détecteur (80) comportant :

un moyen destiné à capter une première force de champ magnétique statique (10) et à produire un premier signal de capteur qui est une fonction de la première force de champ magnétique statique ;
un moyen destiné à capter une seconde force de champ magnétique statique (20) et à produire un second signal de capteur qui est une fonction de la seconde force de champ magnétique statique, le moyen destiné à capter la première force de champ magnétique statique (10) et le moyen destiné à capter la seconde force de champ magnétique statique (20) étant séparés par une distance prédéterminée ;
un moyen destiné à recevoir le premier signal de capteur (12, 14) et à produire un premier signal de détection qui est une fonction du premier signal de capteur ;
un moyen destiné à recevoir le second signal de capteur (22, 24) et à produire un second signal de détection qui est une fonction du second signal de capteur ;
un moyen destiné à recevoir les premier et second signaux de détection (40) et à produire un signal différentiel qui est une fonction de la différence entre le premier signal de détection et le second signal de détection ; et
un moyen destiné à recevoir et à indiquer une valeur (62, 63, 72) pour le signal différentiel.

2. Système selon la revendication 1, dans lequel le moyen destiné à capter la première force de champ magnétique statique (10) et à produire le premier signal de capteur, et le moyen destiné à capter la seconde force de champ magnétique statique (20) et à produire le second signal de capteur comprennent :

un circuit d'attaque (30) de capteur de force de champ magnétique statique destiné à produire un signal d'attaque ; un premier capteur (10) de force de champ magnétique statique destiné à recevoir le signal d'attaque et à produire ainsi le premier signal de capteur ;
un second capteur (20) de force de champ magnétique statique destiné à recevoir le signal d'attaque et à produire ainsi le second signal de capteur.

3. Système selon la revendication 2, dans lequel le circuit d'attaque (30) des capteurs de force de champ magnétique statique comporte un oscillateur (30a) et des transistors de sortie (30b) qui peuvent être commutés en alternance par l'oscillateur et produisent ainsi le signal d'attaque, le premier capteur (10) de force de champ magnétique statique comportant un premier capteur toroïdal (81a) à noyau saturable qui comprend un premier enroulement d'excitation (10c) destiné à recevoir le signal d'attaque et un premier enroulement de détection (10b) destiné à produire le premier signal de capteur, et le second capteur (20) de force de champ magnétique statique comportant un second capteur toroïdal (81b) à noyau saturable qui comprend un second enroulement d'excitation (20c) destiné à recevoir le signal d'attaque et un second enroulement de détection (20b) destiné à produire le second signal de capteur.

4. Système selon l'une quelconque des revendications précédentes, dans lequel le moyen destiné à recevoir le premier signal de capteur (12, 14) et à

produire le premier signal de détection comporte un premier amplificateur (12) destiné à recevoir le premier signal de capteur et à produire un premier signal amplifié qui est proportionnel au premier signal de capteur, et un premier intégrateur (14) destiné à recevoir le premier signal amplifié et à produire le premier signal de détection, et dans lequel le moyen destiné à recevoir le second signal de capteur (22, 24) et à produire le second signal de détection comporte un second amplificateur (22) destiné à recevoir le second signal de capteur et à produire un second signal amplifié qui est proportionnel au second signal de capteur, et un second intégrateur (24) destiné à recevoir le second signal amplifié et à produire le second signal de détection.

5. Système selon l'une quelconque des revendications précédentes, dans lequel le moyen destiné à recevoir et à indiquer une valeur (62, 63, 72) pour le signal différentiel comporte un circuit à amplitude (60) destiné à recevoir le signal différentiel et à produire un signal d'amplitude qui est proportionnel à l'amplitude du signal différentiel, un circuit d'attaque (62) d'affichage visuel destiné à recevoir le signal d'amplitude et à produire un signal d'affichage visuel, et un afficheur visuel (66) destiné à recevoir et indiquer visuellement le signal d'affichage visuel.

6. Système selon la revendication 5, dans lequel le circuit d'attaque (62) d'affichage visuel comporte un circuit d'attaque d'afficheur à échelons à diodes lumineuses, et l'afficheur visuel (66) comprend un afficheur à échelons à diodes lumineuses.

7. Système selon la revendication 5, dans lequel le moyen destiné à recevoir et indiquer une valeur (62, 63, 72) pour le signal différentiel comporte en outre un générateur (63) de son destiné à recevoir le signal d'amplitude et à produire un signal de son qui est une fonction du signal d'amplitude, et un haut-parleur (67) destiné à recevoir et indiquer de façon audible le signal de son.

8. Système selon la revendication 5, dans lequel le moyen destiné à recevoir et indiquer une valeur (62, 63, 72) pour le signal différentiel comporte en outre un circuit à polarité (70) destiné à recevoir le signal différentiel et à produire un signal de polarité qui est une fonction de la polarité du signal différentiel, un circuit d'attaque (72) d'affichage de polarité destiné à recevoir le signal de polarité et à produire un signal d'affichage de polarité, et un afficheur (74) de polarité destiné à recevoir et indiquer visuellement le signal d'affichage de polarité.

9. Système selon l'une quelconque des revendications précédentes, comportant en outre un moyen destiné à commander, contrôler et étalonner automatiquement le moyen destiné à capter la première force de champ magnétique statique (20) et à produire le premier signal de capteur, le moyen destiné à capter la seconde force de champ magnétique statique (10) et à produire le second signal de capteur, le moyen destiné à recevoir le premier signal de capteur (12, 14), et à produire le premier signal de détection, le moyen destiné à recevoir le second signal de capteur (22, 24) et à produire le second signal de détection, le moyen destiné à recevoir les premier et second signaux de détection et à produire le signal différentiel, et le moyen destiné à recevoir et indiquer une valeur (62, 63, 72) pour le signal différentiel.

10. Système selon la revendication 9, dans lequel le moyen de commande, de contrôle et d'étalonnage automatiques comprend un microprocesseur (50).

11. Système selon l'une quelconque des revendications précédentes, dans lequel le signal d'attaque, les premier et second signaux de capteur, les premier et second signaux de détection et le signal différentiel sont des vecteurs.

12. Système selon la revendication 11, dans lequel le moyen destiné à capter la première force de champ magnétique statique (10) comporte :

un oscillateur (226) d'axe x qui produit une composante x du premier signal de capteur, l'oscillateur d'axe x comportant un capteur inductif (226a) à noyau bobiné, la composante x étant une fonction de l'inductance du capteur (226a), l'inductance du capteur (226a) étant une fonction de la première force de champ magnétique statique ;
un oscillateur (227) d'axe y qui produit une composante y du premier signal de capteur, l'oscillateur d'axe y comportant un capteur inductif (227a) à noyau bobiné, la composante y étant une fonction de l'inductance du capteur (227a), l'inductance du capteur (227a) étant une fonction de la première force du champ magnétique statique ; et
un oscillateur (228) d'axe z qui produit une composante z du premier signal de capteur, l'oscillateur d'axe z comportant un capteur inductif (228a) à noyau bobiné, la composante z étant une fonction de l'inductance du capteur (228a), l'inductance du capteur (228a) étant une fonction de la première force de champ magnétique statique ; et dans lequel le moyen destiné à capter la seconde force de champ magnétique statique (20) comprend :
un oscillateur (216) d'axe x qui produit une composante x du second signal de capteur, l'oscillateur d'axe x comportant un capteur in-

ductif (216a) à noyau bobiné, la composante x étant une fonction de l'inductance du capteur (216a), l'inductance du capteur (216a) étant une fonction de la seconde force de champ magnétique statique ;

un oscillateur (217) d'axe y qui produit une composante y du second signal de capteur, l'oscillateur d'axe y comportant un capteur inductif (217a) à noyau bobiné, la composante y étant une fonction de l'inductance du capteur (217a), l'inductance du capteur (217a) étant une fonction de la seconde force de champ magnétique statique ; et

un oscillateur (218) d'axe z qui produit une composante z du second signal de capteur, l'oscillateur d'axe z comportant un capteur inductif (218a) à noyau bobiné, la composante z étant une fonction de l'inductance du capteur (218a), l'inductance du capteur (218a) étant une fonction de la seconde force de champ magnétique statique.

13. Système selon l'une des revendications 11 et 12, dans lequel le moyen destiné à recevoir le premier signal de capteur comprend :

un compteur (246) de fréquence d'axe x qui reçoit une composante x du premier signal de capteur et produit une composante x du premier signal de détection ;

un compteur (247) de fréquence d'axe y qui reçoit une composante y du premier signal de capteur et produit une composante y du premier signal de détection ; et

un compteur (248) de fréquence d'axe z qui reçoit une composante z du premier signal de capteur et produit une composante z du premier signal de détection ; et

dans lequel le moyen destiné à recevoir le second signal de capteur comporte :

un compteur (236) de fréquence d'axe x qui reçoit une composante x du second signal de capteur et produit une composante x du second signal de détection ;

un compteur (237) de fréquence d'axe y qui reçoit une composante y du second signal de capteur et produit une composante y du second signal de détection ; et

un compteur (238) de fréquence d'axe z qui reçoit une composante z du second signal de capteur et produit une composante z du second signal de détection.

14. Système selon l'une quelconque des revendications précédentes, dans lequel le moyen destiné à recevoir les premier et second signaux de détection et à produire le signal différentiel comprend un amplificateur différentiel.

15. Procédé de détection de la position d'un aimant (91) associé à un tube médical (90) à l'intérieur du corps d'un patient, comprenant :

le fait de capter une première force de champ magnétique statique à une première distance de l'aimant (91) ;

le fait de capter une seconde force de champ magnétique statique à une seconde distance de l'aimant qui est plus grande que la première distance ;

le fait de produire un premier signal de capteur qui est une fonction de la première force de champ magnétique statique ;

le fait de produire un second signal de capteur qui est une fonction de la seconde force de champ magnétique statique ;

le fait de recevoir les premier et second signaux de capteur et de produire un signal différentiel qui est une fonction de la différence entre la première force de champ magnétique statique et la seconde force de champ magnétique statique ;

le fait de recevoir et d'indiquer une valeur pour le signal différentiel ; et

le fait de déterminer la position du tube médical (90) en faisant varier les première et seconde distances jusqu'à ce que la valeur la plus grande pour le signal différentiel soit indiquée.

16. Procédé selon la revendication 15, dans lequel le premier signal de capteur, le second signal de capteur et le signal différentiel sont des vecteurs.

17. Procédé selon la revendication 15 ou 16, dans lequel le fait de produire le premier signal de capteur comprend :

le fait d'accorder un oscillateur (226) d'axe x avec l'inductance d'un capteur inductif associé (226a) à noyau bobiné, l'inductance étant une fonction de la première force de champ captée, et de produire une composante x du premier signal de capteur à partir de l'oscillateur (226) d'axe x ;

le fait d'accorder un oscillateur (227) d'axe y avec l'inductance d'un capteur inductif associé (227a) à noyau enroulé, dans lequel l'inductance est une fonction de la première force de champ captée, et de produire une composante y du premier signal de capteur à partir de l'oscillateur (227) d'axe y ; et

le fait d'accorder un oscillateur (228) d'axe z avec l'inductance d'un capteur inductif associé (228a) à noyau enroulé, dans lequel l'inductan-

ce est une fonction de la première force de champ captée, et de produire une composante z du premier signal de capteur à partir de l'oscillateur (228) d'axe z ; et dans lequel le fait de produire le second signal de capteur comprend :
le fait d'accorder un oscillateur (216) d'axe x avec l'inductance d'un capteur inductif associé (216a) à noyau enroulé, dans lequel l'inductance est une fonction de la seconde force de champ captée, et de produire une composante x du second signal de capteur à partir de l'oscillateur (216) d'axe x,
le fait d'accorder un oscillateur (217) d'axe y avec l'inductance d'un capteur inductif associé (217a) à noyau enroulé, dans lequel l'inductance est une fonction de la seconde force de champ captée, et de produire une composante y du second signal de capteur à partir de l'oscillateur (217) d'axe y ; et
le fait d'accorder un oscillateur (218) d'axe z avec l'inductance d'un capteur inductif associé (218a) à noyau enroulé, dans lequel l'inductance est une fonction de la seconde force de champ captée, et de produire une composante z du second signal de capteur à partir de l'oscillateur (218) d'axe z.

18. Procédé selon l'une quelconque des revendications 15 à 17, dans lequel la réception des premier et second signaux de capteur et la production du signal différentiel comprend :

le fait de déterminer les fréquences respectives d'une composante x, y et z du premier signal de capteur ;
le fait de déterminer les fréquences respectives d'une composante x, y et z du second signal de capteur ;
le fait de déterminer les différences entre les fréquences de la composante x, y et z du premier signal de capteur et les fréquences correspondantes de la composante x, y et z du second signal de capteur ; et
le fait de produire le signal différentiel égal à une amplitude et une polarité des différences.

19. Procédé selon l'une quelconque des revendications 15 à 18, comprenant en outre le fait de contrôler des variations des première et seconde forces de champ magnétique statique pour vérifier la position du tube médical.

20. Procédé de vérification de la position d'un aimant (91) associé à un tube médical (90) à l'intérieur du corps d'un patient, comprenant :

le fait de capter une première force de champ magnétique statique à une première distance de l'aimant (91) ;
le fait de capter une seconde force de champ magnétique statique à une seconde distance de l'aimant (91) qui est plus grande que la première distance ;
le fait de produire un premier signal de capteur qui est une fonction de la première force de champ magnétique statique ;
le fait de produire un second signal de capteur qui est une fonction de la seconde force de champ magnétique statique ;
le fait de recevoir les premier et second signaux et de produire un signal différentiel qui est une fonction de la différence entre la première force de champ magnétique statique et la seconde force de champ magnétique statique ;
le fait de recevoir et d'indiquer la polarité du signal différentiel ; et
le fait de manipuler l'aimant (91) jusqu'à ce que la polarité indiquée du signal différentiel change.

21. Procédé selon la revendication 20, dans lequel l'aimant (91) est manipulé en étant tourné.

22. Procédé selon la revendication 20 ou 21, comprenant en outre le fait de contrôler des variations des première et seconde forces de champ magnétique statique pour vérifier davantage la position de tube médical (90).

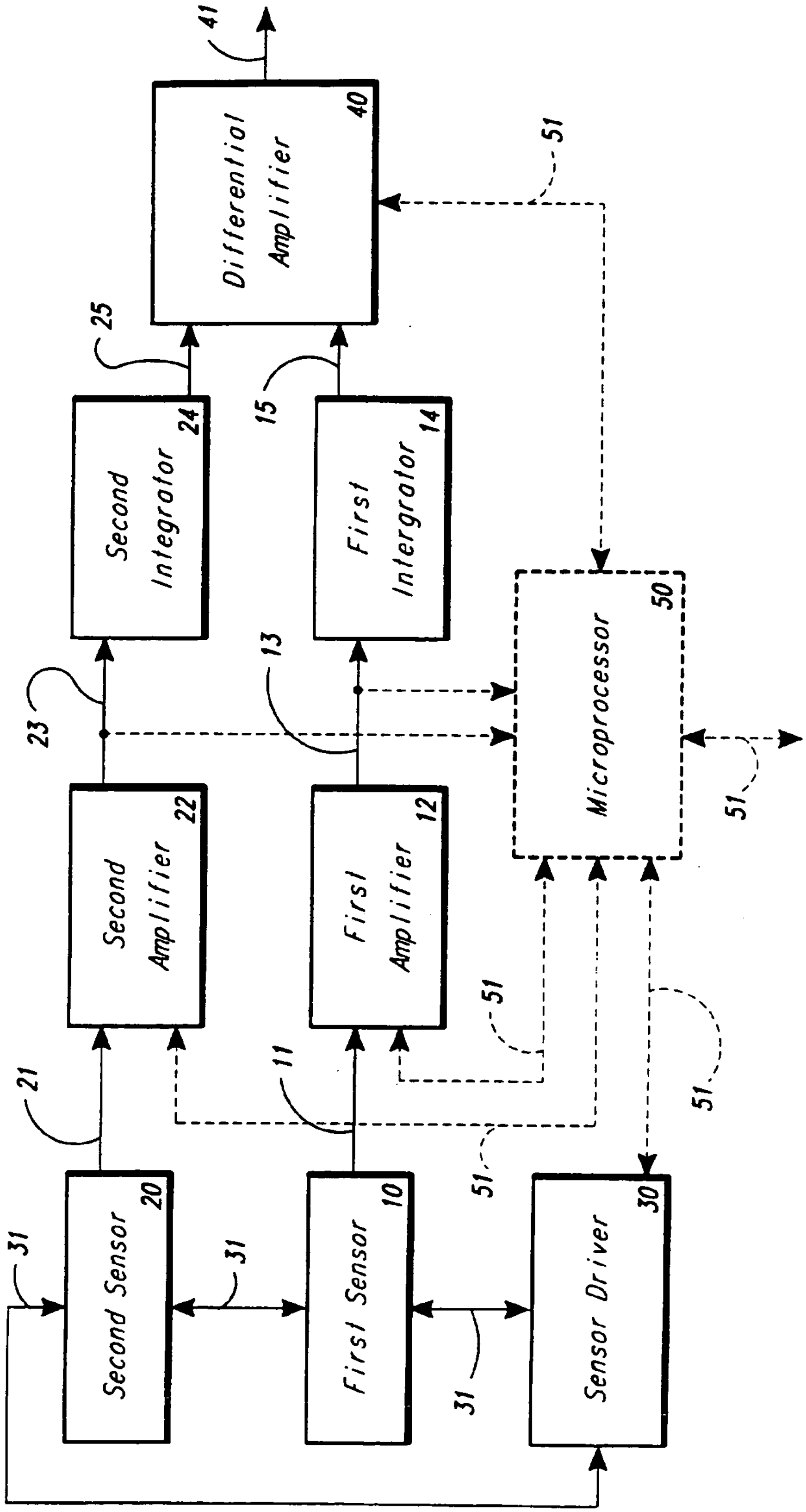
Differential Amplifier
40
41
51
Second Integrator
24
25
First Intergrator
14
15
Microprocessor
50
13
23
Second Amplifier
22
First Amplifier
12
51
11
21
51
51
Second Sensor
20
First Sensor
10
Sensor Driver
30
31
31
31

Fig. 1A

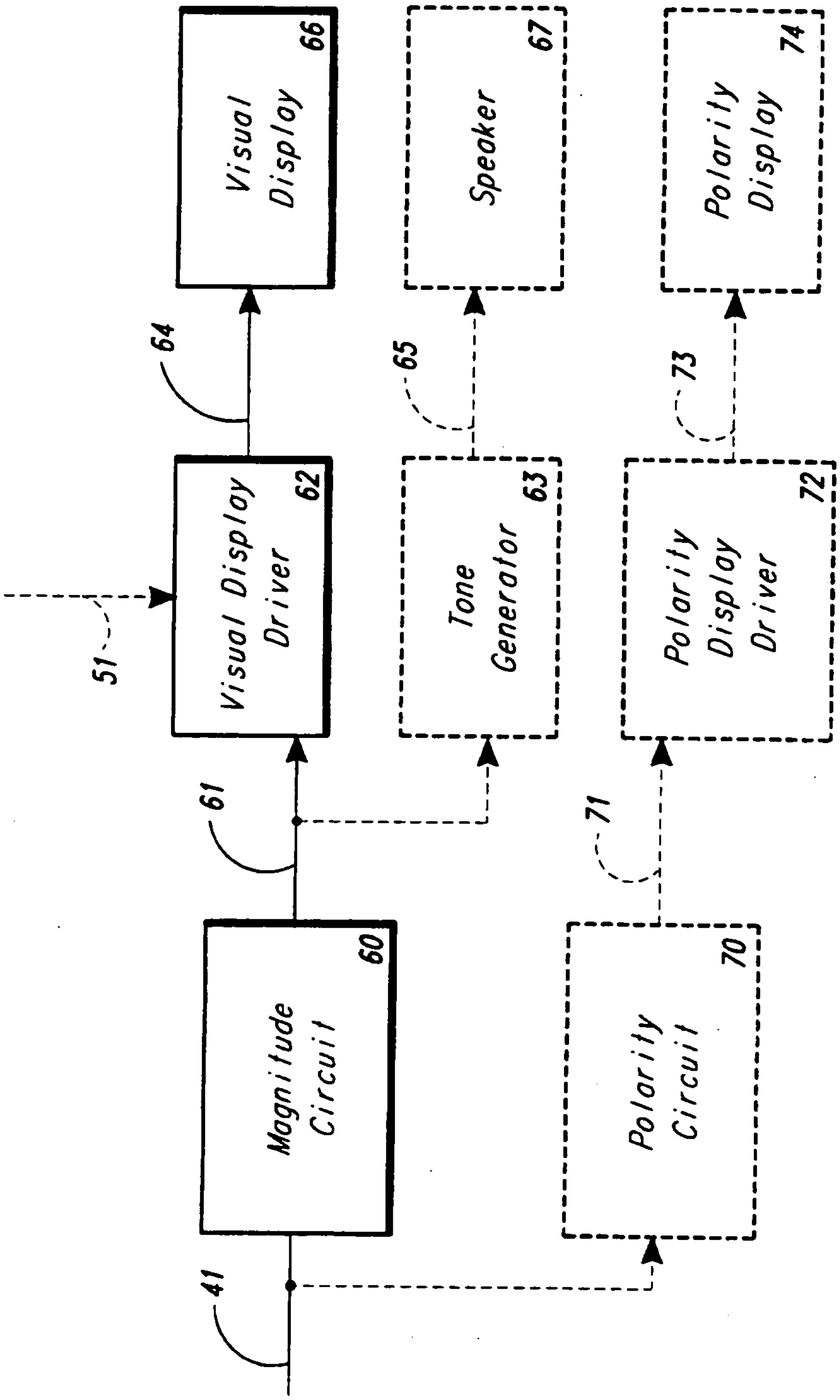
Magnitude Circuit
60
41
61
Visual Display Driver
62
51
64
Visual Display
66
Tone Generator
63
65
Speaker
67
Polarity Circuit
70
71
Polarity Display Driver
72
73
Polarity Display
74

Fig. 1B

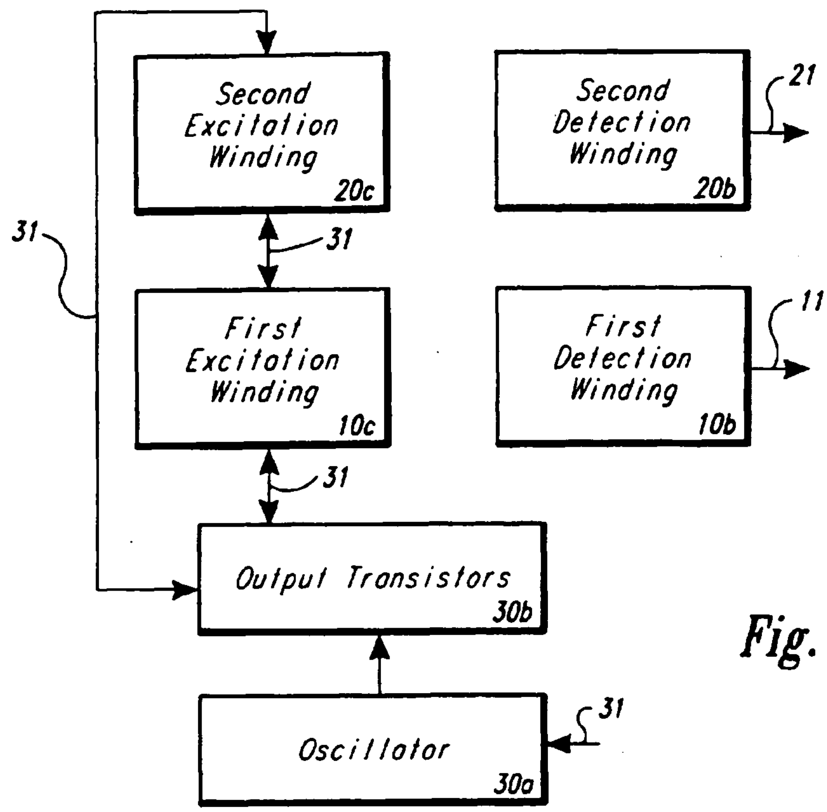
Second Excitation Winding
20c
Second Detection Winding
20b
21
31
31
First Excitation Winding
10c
First Detection Winding
10b
11
31
Output Transistors
30b
Oscillator
30a
31

Fig. 2

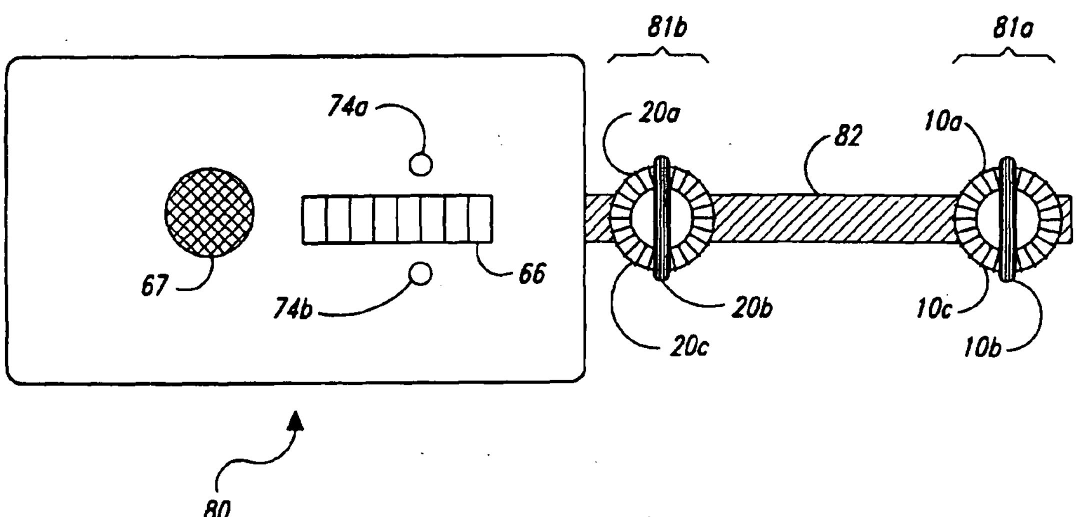
81b
81a
74a
20a
10a
82
67
66
74b
20b
10c
20c
10b
80

Fig. 3

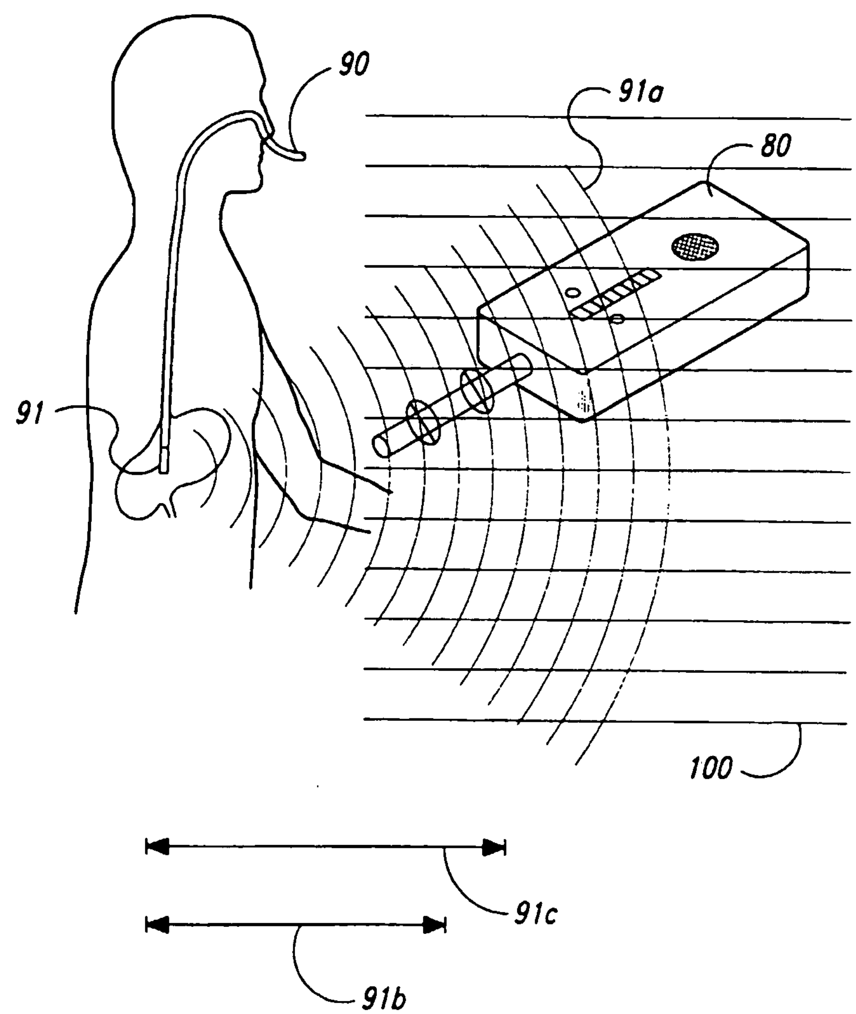

Fig. 4

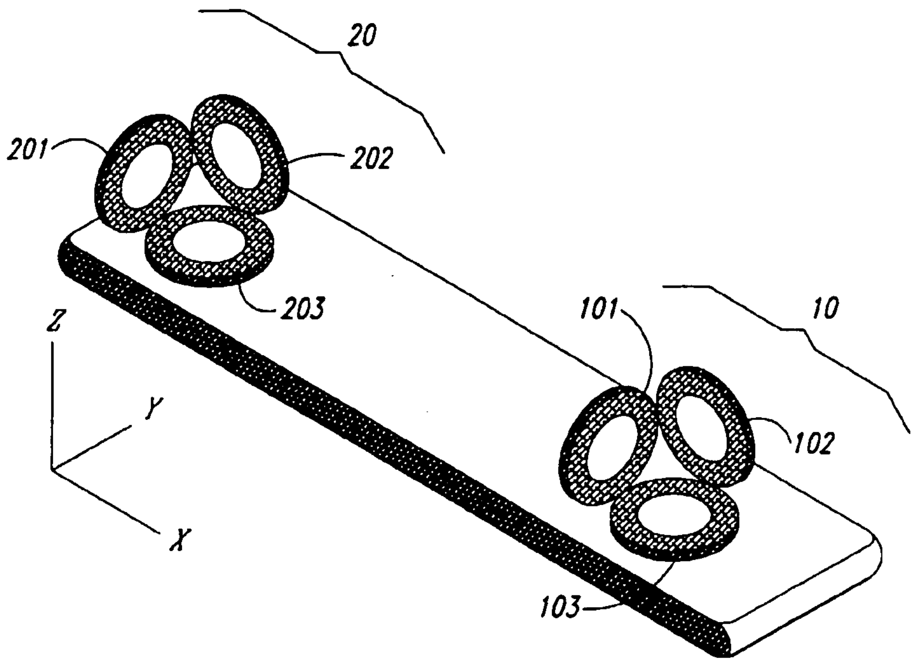

Fig. 5

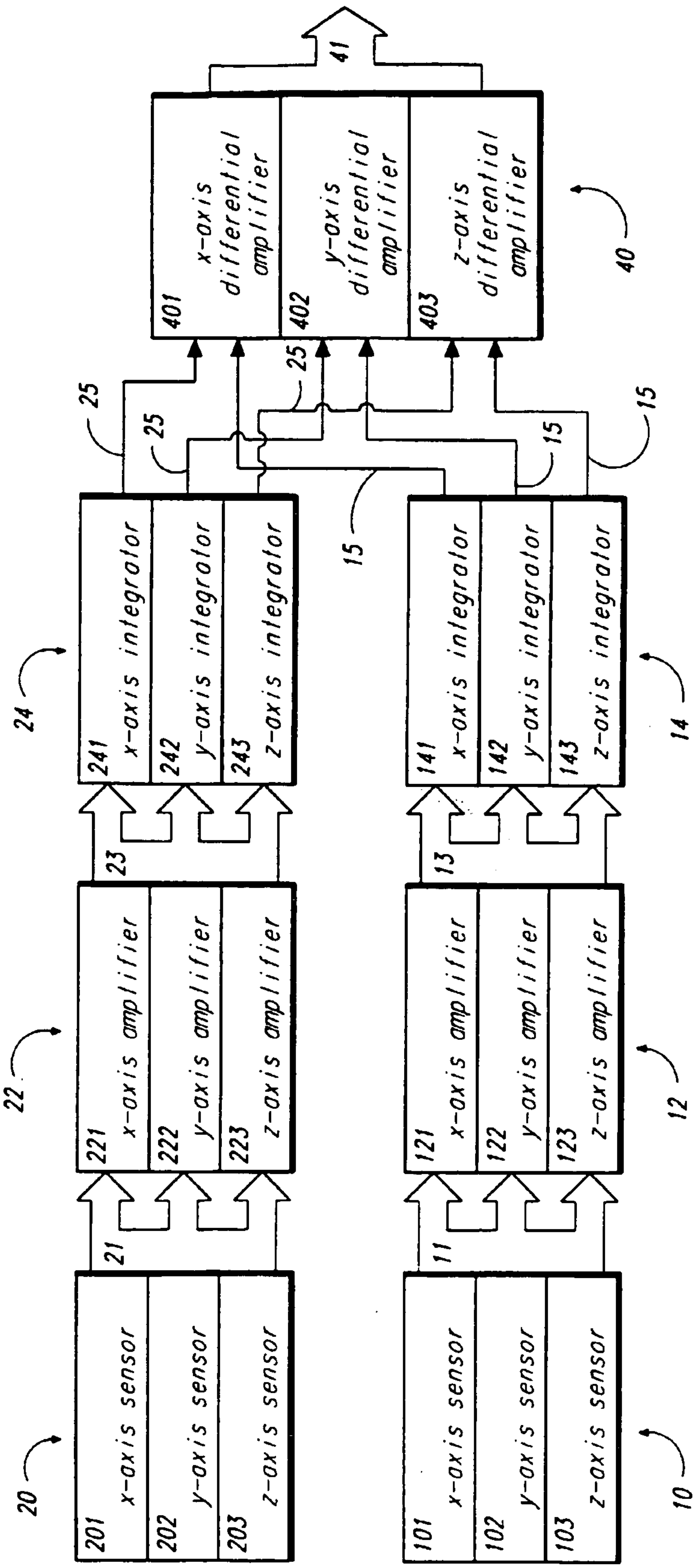
x-axis differential amplifier
y-axis differential amplifier
z-axis differential amplifier
x-axis integrator
y-axis integrator
z-axis integrator
x-axis amplifier
y-axis amplifier
z-axis amplifier
x-axis sensor
y-axis sensor
z-axis sensor
401
402
403
40
41
241
242
243
24
25
141
142
143
14
15
221
222
223
22
23
121
122
123
12
13
201
202
203
20
21
101
102
103
10
11

Fig. 6

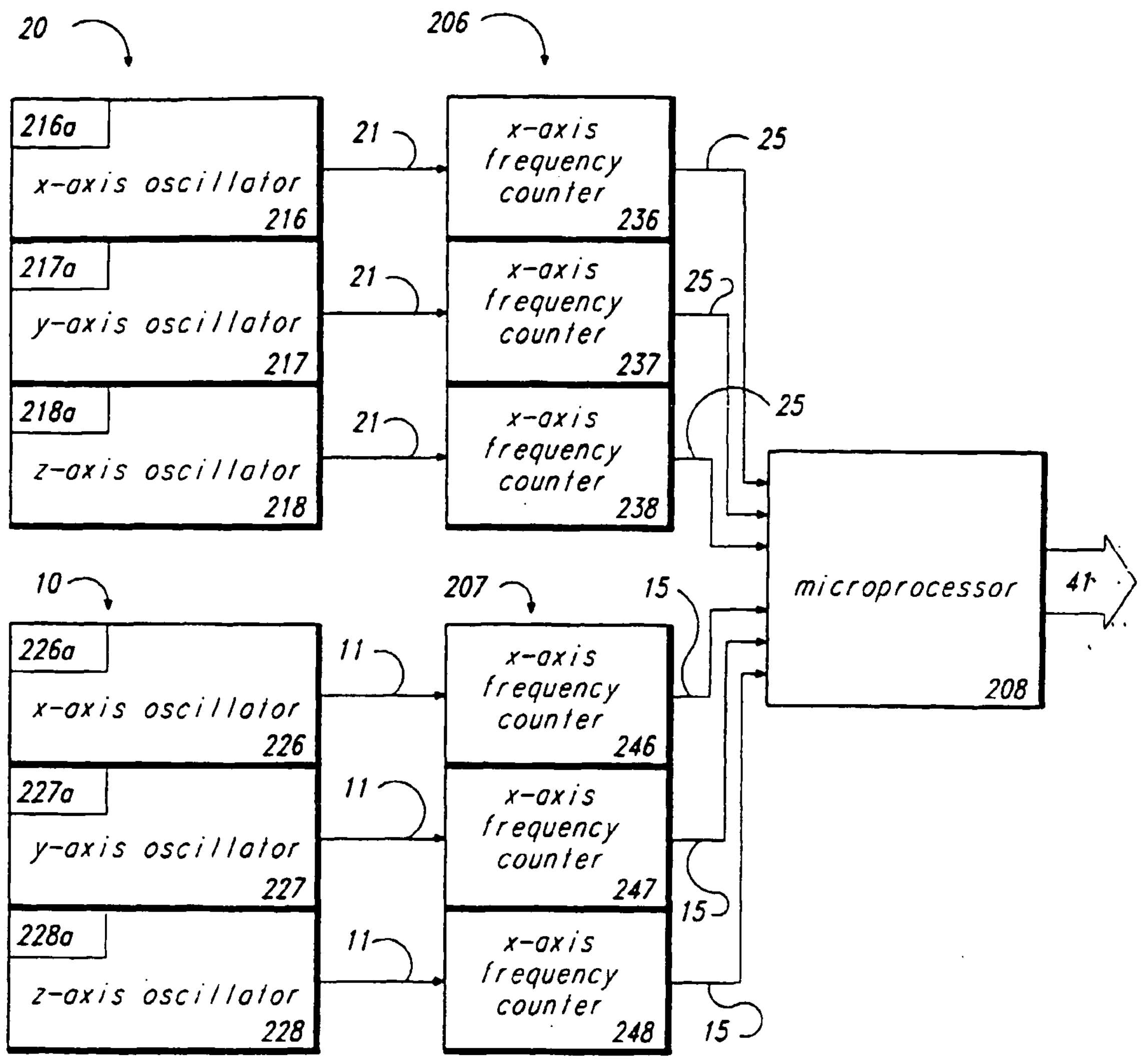
20
206
216a
x-axis oscillator
216
21
x-axis frequency counter
236
25
217a
y-axis oscillator
217
21
x-axis frequency counter
237
25
218a
z-axis oscillator
218
21
x-axis frequency counter
238
25
microprocessor
208
41
10
207
15
226a
x-axis oscillator
226
11
x-axis frequency counter
246
227a
y-axis oscillator
227
11
x-axis frequency counter
247
15
228a
z-axis oscillator
228
11
x-axis frequency counter
248
15

Fig. 7